JOURNAL
OF THE
WASHINGTON ACADEMY OF SCIENCES

VOL. 47 JULY 1957 NO. 7

THE ROLE OF THE CIVIL ENGINEER

(By our deeds they shall know us)

THE CIVIL ENGINEER has had a place in the civilization of this world ever since the first crude shelter was built in bygone centuries to provide protection against the elements and his foes. He has progressed far since the days of his first hut, for now he has a place of first importance in the planning, design, erection, and operation of atomic-energy facilities and devices. Our supersonic aircraft would be unable to take off and land if it were not for the civil engineer and the precise methods he uses in the design and construction of airfields. Projected missiles require his services in the preparation of their launching bases. By his water-supply works he has quenched the thirst of thousands and supplied industry with their most important commodity.

The past is prologue. What does the future hold for the civil engineer? We know the civil engineer has and will continue to have a great and vital role in the future of the world, for he has had unusual and thorough preparation for his profession; he has the basic integrity needed for work with his fellow-men; he performs real service to all humanity; he is dedicated to his profession.

The National Capital Section of the American Society of Civil Engineers, in an effort to describe to the members of the Washington Academy of Sciences some of the various activities of civil engineers, requested a number of their members to write about their chosen field of endeavors. The articles that follow depict only a few of the facets into which the field of civil engineering is divided.

Civil-Engineering Research

By G. E. Burnett, Bureau of Reclamation, Denver, Colo.

Civil engineering is not always recognized as being one of the more imaginative of the scientific professions. Therefore, to some it may come as a surprise that much can be said about civil-engineering research. The fact is that good civil engineering demands a high degree of resourcefulness and imagination, and civil engineers the world over are deeply engrossed with research. They are acutely aware of the need for finding better ways of doing things.

Economy with safety is the civil engineer's byword. His structures must not fail, yet he is compelled to gain in economy and so must continually seek bolder designs, reduction in costs in construction materials, and development of more efficient methods of construction. He can not take undue risks in the prototype; thus, laboratory and field research has become a principal tool in gaining these objectives.

Research is performed in all phases of civil engineering—in buildings, bridges, railroads, highways, dams—in planning, designing, construction, operating, and maintaining—in all sorts of construction materials. The field is much too broad for complete coverage here. Typical, however, is the research conducted by the Bureau of Reclamation, a civil-engineering organization that for 55 years has been building irrigation and multipurpose water projects in the West.

Much diversity will be found in Reclamation research, because much diversity exists in its structures. Dams, large and small, earth and concrete, low head and high head. Canals, lined and unlined. Canal structures, diversion works, checks, drops, turnouts, siphons. Hydroelectric plants, pumping plants, gravity and pressure pipelines, electric transmission lines, substations, bridges, railroad and highway relocations, Government camps and towns. Individual structures must be planned and built for competency, serviceability, and safety under widely varying conditions of foundation, topography, climate, and operating conditions. With all, the Bureau is under the constant stimulus of developing project facilities as economically as possible and within the water users' ability to repay the costs of construction, as required by Reclamation law.

Reclamation research is a coordinated endeavor in design studies and analysis, in laboratory tests and investigations, and in field observations and surveys. The analytical approach includes application of special mathematical techniques coupled with conventional design procedures. Laboratory research is essential to the determination of the properties and the best methods for the use of construction materials, in analyzing and predicting structural behavior, and in determining operating characteristics. Field research is applied when the limitations of the laboratory are exceeded and extends the knowledge of functions of structures and leads to improved and more economical operation of completed works.

Bureau research activity is particularly identified with the work and accomplishments of the Bureau's central engineering laboratories under the direction of the Assistant Commissioner and Chief Engineer in Denver. The laboratories have made major contributions in virtually every phase of Reclamation engineering advancement. In the fields of hydraulic research, in structural testing, and in investigations of construction materials, laboratory effort has increased the flexibility and scope of design and construction methods. Laboratory research has not only developed new approaches and solutions to engineering problems, but has been instrumental in achieving major economies. The engineering laboratories are regarded as indispensable aids in the planning, designing, building, and operation of reclamation works.

Hydraulic laboratory research embraces a wide variety of specialized problems. Hydraulic structures such as dams, spillways, outlet works, stilling basins, canal chutes and siphons, conduits, and hydraulic ma-

chinery and appurtenances are studied in working models for adequacy of performance and for determination of forces acting on them and their prototypes. Such model tests have led the way to great improvements in hydraulic operating characteristics, safety in operation, and economies of design. The solution of specific problems has also yielded a wide range of hydraulic data and experience of value in the solution of future problems.

Hydraulic research techniques have played an important part in modifying designs and altering flow conditions to obtain desired discharge capacities for hydraulic structures. Ways of minimizing the destructive effects of cavitation and subsequent costly repairs to structures and equipment have been developed. Studies pertaining to the control and release of water from conduits under high pressure have resulted in more economical, improved, and cavitation-free gate and valve designs. Reduction in the size of water passages has made economies possible in many structures when laboratory studies pointed out practical design modifications. Dimensions of spillways have been decreased in many instances, and the operation of these features has been improved. Recent comprehensive studies of stilling basins and appurtenant facilities have extended the knowledge of dissipating the energy of falling water and will undoubtedly enrich the art of hydraulic engineering. Favorable progress has been made in river channel stabilization and the control of sediment at canal headworks at diversion dams.

The hydraulic laboratory has extended its usefulness by the application of electronic analogs to solve various problems, including the control of surges in pipeline irrigation distribution systems. Such application has been valuable also in salinity studies.

A primary requisite to sound design and construction is structural research conducted for the accurate measurement of stresses, strain, deflection, creep, and other physical effects developed in structures in use. Tests on models of girders, columns, frames, gates, and other structures or structural parts are invaluable adjuncts to safe and economical designs. Structural research has also been applied profitably to the study of foundations and characteristics of materials, particularly in the correlation of mineralogical and physical properties of rock.

In concrete technology, noteworthy progress has been made in the solution of the cracking problem that results from reaction of the alkalies in cement with certain aggregates, in the use of pozzolanic materials to improve concrete and reduce cement content, in the introduction of air entrainment in concrete to improve workability and durability, and in the successful use of lean concrete. Laboratory research on concrete materials has contributed to the development of different types of portland cement, each having special properties needed for particular purposes; e.g., one that will resist the disruptive attack of sulfates in soil or water. From such researches have come also basic criteria for control of mixing, transporting, and placing of concrete, and for the proportioning of materials in concrete for adequate quality and workability. Notable progress has also been made in the analyses of thermal properties of concrete, in the measurement of volume change, and in the studies of durability, permeability, strength, elasticity, creep, and other properties of concrete.

Major economies resulting from such concrete research have been demonstrated. Since the establishment of the Bureau laboratories in 1930, it is conservatively estimated that an average of one-tenth barrel of cement has been saved in each of some 50 million cubic yards of concrete placed in Bureau structures, representing a savings of perhaps 10 million dollars. The development of inexpensive pozzolans for use in concrete has resulted in an improved concrete for a number of large dams and in additional savings in cement. The addition of fly ash as a pozzolan to the concrete of Hungry Horse and Canyon Ferry Dams, two large dams built in Montana a few years ago, alone reduced the cost of construction by several million dollars. Without an ample background of laboratory

research and the attending proof of design quality, the use of fly ash could hardly have been ventured in such important structures.

Perhaps no area of civil-engineering research has seen a greater expansion in recent years than has soil mechanics. Great progress has been made in methods of evaluating shear, compaction, and permeability properties of soils. Procedures have been developed for chemical and microscopic examinations. Soils research and its effect on the extension of knowledge of soil behavior have been important factors in the development of improvements in the design and construction of earth dams and other earth embankments. The introduction of relatively inexpensive heavy-type compacted earth linings for canals received its major impetus through laboratory investigations, as did the jetting and vibrating method of compacting cohesionless soils for backfill. Better exploration and testing techniques have led to more economical foundation designs for a variety of structures. A laboratory-developed atomic radiation device now gives promise in measuring soil density and moisture content in situ and in measuring reservoir sediment density.

FIG. 1.—Testing of products destined for installation on Bureau projects is an important activity of the engineering laboratories. Here, laboratory engineers discuss the procedures to be followed in testing this 66-inch diameter reinforced concrete pipe under the 5-million pound universal testing machine.

Research engineers have contributed to the knowledge and application of other materials, including paints and coatings of many types, bituminous materials, rubber waterstops, and metals. Bentonites and other clay minerals have been studied for

their usefulness for construction applications as in canal lining. Tests designed to evaluate protective coatings and their ability to prevent corrosion have been valuable aids to the utilization of new materials and to the more effective use of standard materials.

Of concern to the civil engineer working on irrigation problems is the matter of weed control, especially aquatic weeds that clog canals. Through its weed control research program, the Bureau has made rapid strides in determining the effectiveness and economy of weed killers. Studies of growth habits of weeds have been helpful to developing better ways of killing them. Recently laboratory research has utilized radioactive isotopes to study plant physiology and the effect of herbicides on aquatic and land-type weeds. Laboratory researchers in cooperation with physiologists of the Bureau of Plant Industry developed an inexpensive aromatic solvent weed killer that is now widely used to control aquatic weeds in irrigation canals.

Research is also of importance in the field where new developments can be observed under actual operating conditions. A variety of field programs has been carried out as a joint endeavor of project offices, design engineers, and the Denver laboratories. This flexible, closely cooperative effort has led to improved structure performance and to furtherance of the economies indicated in laboratory research.

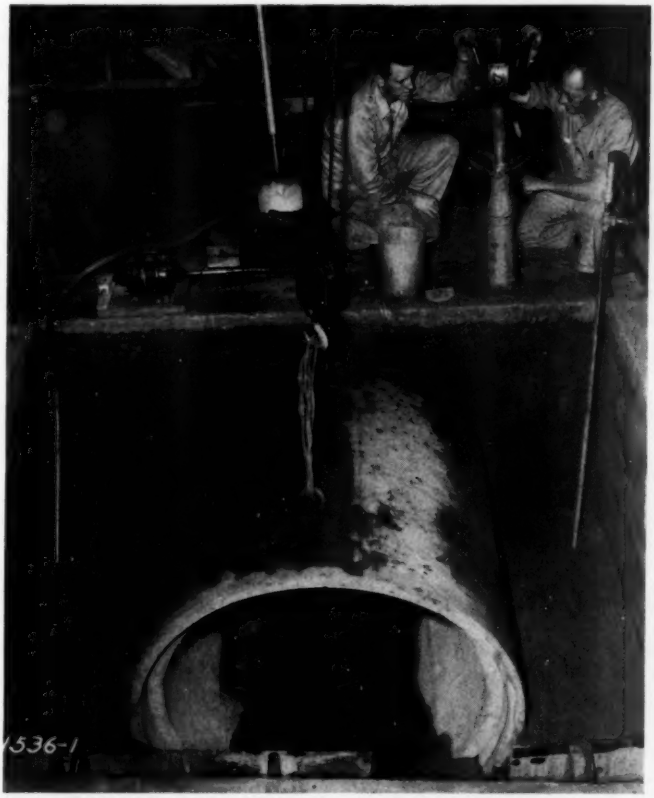

FIG. 2.—An engineer and his aid in the earth-materials laboratory are shown here carrying out tests to develop jetting and vibrating methods for consolidating cohesionless soils around concrete pipe.

Such coordinated research is typified by

the development of lower-cost linings for irrigation canals and laterals. Prefabricated asphalt, buried asphaltic membrane, and heavy-type compacted earth linings, among other materials, have been successfully introduced, following intensive laboratory investigation and field study. Marked improvement in construction techniques and reduction of costs of canal lining construction have resulted.

A water measurement refinement and standardization program, under way for several years, has added to the knowledge of performance of measuring devices and promises improved operations on irrigation projects.

With the cooperation of other agencies, the major problem of control of reservoir evaporation is under intensive study in the laboratory and in the field. Monomolecular layers of some organic compounds appear to have considerable potential usefulness in controlling evaporation from open reservoirs. In evaporation pans, a monomolecular film reduced evaporation losses as much as 64 percent—which may have far-reaching implications especially in the water-scarce West.

Drainage of irrigable lands has been an important research item in the field, particularly in recent years. Improvement of techniques of analyzing the physics and chemistry of soils has made possible great strides in drainage practices and appraisal of drainage possibilities. Reclaiming of numerous areas on which alkaline and saline conditions prevail and adoption of measures to prevent excessive alkalinity and salinity in soils have followed from drainage investigations. The possibilities of electroreclamation of alkaline soils is currently under close study.

In other directions, field research has been important in the study of electrical methods for inhibiting corrosion of buried and submerged metalwork, in gathering data on the effect of ice pressure on structures, in the measurement of seepage from canals, and in the stabilization of expansive soils by electrochemical techniques.

Thus, research is seen to be a productive and important factor in Reclamation's design and construction programs. It has given impetus to development of new engineering applications, introduction of new materials, and to amplification and strengthening of existing procedures. It has also contributed to major economies in design and construction.

Research is properly a cooperative enterprise, and so cooperation with technical societies, other Government agencies, industry, colleges and universities, and the public in general is an important and valuable phase of our research endeavor. The results of Bureau investigations are fully disclosed through a variety of laboratory reports, engineering monographs, specialist manuals, and other writings. Hundreds of papers summarizing the findings of our research have been published in the journals of the major technical societies both in this country and abroad. The names of many of our engineers appear on the rosters of these societies, and the Bureau is well represented in important technical committee assignments and officerships.

We in the Bureau expect that research will continue to have considerable influence on our activities for the future. Water must now be conveyed and distributed in increasingly larger quantities and over great distances and difficult terrain. Certain project developments may embrace new transbasin diversions of river waters. In general, the easier-to-build projects have been constructed. Those in the future will inevitably become increasingly difficult. There is no doubt that the Bureau's research engineers will be faced with many challenging problems in the years ahead. Other civil engineering organizations must find themselves in a similar situation, and they also will be looking to research for the answers. Civil engineering research is indeed an active and growing part of the scientific world.

The Role of the Civil Engineer in Hydraulics

By C. C. McDonald (American Society of Civil Engineers)

Now there was no water for the congregation; and they assembled together against Moses and Aaron. And the people contended with Moses, and said, "Would that we had died when our brethren died before the Lord. Why have you brought the assembly of the Lord into this wilderness, that we should die here, both we and our cattle?" • • • Then Moses and Aaron went from the assembly • • • and the Lord said to Moses, "Take the rod, and assemble the congregation, you and Aaron your brother, and tell the rock before their eyes to yield its water, so you shall give drink to the congregation and their cattle." • • • And Moses lifted up his hand and struck the rock with his rod twice; and water came forth abundantly, and the congregation drank, and their cattle. (Numbers 20: 2–10)

Water is a necessity of life, and its availability has profoundly influenced man's activities throughout the centuries. The struggle for water has indeed been an important part of man's struggle for existence. The earliest known civilizations developed in areas of favorable climate and abundant water supplies. Man could not live and prosper in arid areas until he achieved the necessary skills to dig wells or otherwise provide a water supply. In his efforts to provide for his needs and to put water to greater service, man has developed a considerable amount of technical knowledge about water and its movement, and great skill in its control and use. In our times, many branches of science and engineering participate in this knowledge and contribute to the development of water supplies for man's convenience and pleasure.

In a sense, the story of the development of technical knowledge is the story of the progress of mankind, for no less than law and government has technology been a mark of the civilized world. One might claim with some validity that the level of development of engineering works for the use of water for domestic, irrigation, and transportation purposes has been a measure of the development of civilization. Whether this will continue to be evident in the future, with the great scientific advances that have been made during this generation, is impossible to forecast. Needs for water, however, are very personal and immediate, and the science dealing with its availability and control will continue to play an important role in the welfare of mankind. The hydraulic engineer has a key role in the process of water utilization, because it is he who translates scientific knowledge into practical works for the service of man.

Among the earliest known hydraulic works of substantial magnitude were the irrigation and drainage systems in the valley of the Nile River in Egypt, the construction of which is attributed to Menes, the semilegendary founder of the First Dynasty (about 3200 B. C.). These works mark the beginning of a brilliant period of engineering activity which included erection of the pyramids. In his "Civil Engineering Through the Ages" (Trans. A.S.C.E., vol. CT, 1953, p. 1) C. J. Merdenger states that the significant aspect of Egyptian engineering is that here for the first time is evidence of man building to a plan, instead of haphazardly, and using mathematics to ensure the results desired. This contribution may be slight compared to the works of modern civil engineering, but it is gigantic when compared to the works of primitive man. Archaeologists have discovered evidence of water supply works of other early civilizations, notably the Minoan in the Aegean which probably flourished between 2000 and 1000 B. C., although our knowledge of their works is far from complete.

Later civilizations, the history of which is better documented, made important contributions to the science of hydraulics. The Greek philosophers who attained eminence during a period of several centuries beginning about the sixth century B. C. developed important theoretical concepts that were later put to practical use. For example,

Archimedes (287–212 B. C.), Greek philosopher of Syracuse, developed the fundamentals of hydrostatics. Water systems were developed for several cities during this era. Tyre and other Phoenician cities had elaborate dug wells and stone aqueducts. Many Greek cities were supplied with water from distant sources by means of aqueducts, and the populace was served by beautiful spring houses, fountains, pools, and public baths.

The construction of elaborate and extensive aqueducts was brought to a peak by the Romans during the period 300 B. C. to A. D. 300, Rome built its first water-supply aqueduct about 310 B. C., an underground stone conduit 11 miles long. This was followed 130 years later by a second, built to divert water from the river Anio, a tributary of the Tiber, 40 miles from Rome. This was followed by others, a total of 14. One of them was 60 miles long, was constructed on an appropriate gradient, and crossed valleys on 7 miles of stone arches. Cut stone, brick, and cement were used in their construction. The water system of Rome, a city of perhaps a million people, was indeed a marvel of engineering accomplishment for that day. Copper and lead pipes were utilized to distribute water to the many public fountains, storage tanks, and public baths, as well as to the homes of the wealthy. Frontinus, a water supervisor of Rome, wrote extensively about the water system, described the orifice flow-measuring devices, and mapped the distribution network.

Following the fall of the Roman Empire, nearly 1,000 years elapsed before water systems were developed that were comparable to those of the Romans. By the year 1500 progress was being made in Western Europe in the development of water systems and of some hydraulic machinery. Hand pumps were used to some extent, and water wheels were becoming commonplace. Arab cities of the East and a few cities in Holland and in Germany by this time were using windmills for pumping water. In 1582 Peter Maurice installed on London Bridge a pump driven by water wheels to lift water from the Thames River to the wooden pipe that carried water through the streets of London. Many European cities followed with similar systems. In 1619 a lead-lined wooden aqueduct was built to supplement the water supply for London, and a few years later an aqueduct was constructed to improve the water supply of Paris. A small aqueduct was built in the United States in 1642 to bring water to Boston from nearby springs.

Modern water systems during the past 100 to 150 years have far surpassed those of Rome during the peak of the Roman Empire. The extensive water supply system for New York City was begun in 1842 with the completion of the first Croton aqueduct, followed 50 years later by the second. In 1914 New York completed its extensive Catskill aqueduct, and its fourth, the great Delaware River Aqueduct (completely underground), is now being completed and extended. Such progress has been possible because of technological developments in many fields of endeavor, but the greatest credit is due the hydraulic engineer, both ancient and modern.

Thus, in the development of water supplies for cities, the hydraulic engineer, by whatever name he may have been known in his day, has made important contributions. Hydraulics is involved in the design of dams and storage reservoirs, outlet works, spillways, conduits, distribution systems, and hydraulic machinery. The hydraulic engineer has not been alone in the development of water distribution systems. He has been a partner with engineers of other skills in the design of all features of these systems. Nor, indeed, has the contribution of the hydraulic engineer been limited to water-supply problems.

The origin of the science of hydraulics is of great antiquity, a science that has developed through the accumulated experience and thought of several thousands of years. The elaborate water systems of the Romans showed they possessed some knowledge of the properties of water when at rest and when in motion in pipes and open channels, but we have no record that this knowledge was based on well-defined quantitative laws. A treatise by Stevinus about 1585 appears to follow that of Archimedes. In this treatise the method of obtaining the pressure in a liquid on the sides and base of

a vessel was first demonstrated. Galileo, in 1612, discussed the hydrostatic principles involved in the flotation of bodies in water. Shortly afterward Torricelli made important investigations of the behavior of a vertical jet issuing from an orifice. Since that time numerous investigators have been deducing, by experimental observation and theoretical reasoning, the laws governing various manners of motion of liquids and applying them to the development of the science of hydraulics—Mariotte, Bernoulli, D'Alembert, Poiseuille, and Darcy in France; Rankine, Froude, Osborne, and Reynolds in England; Eytelwein, Weisback, and Kutter in Germany; Venturi in Italy; Francis, Hamilton Smith, Hazen, and a host of less famous others in America.

The special problems involved in determining the availability and occurrence of water have given rise to the closely allied science of hydrology, which is concerned with the laws related to the movement of water through the cycle from atmosphere, to precipitation upon the earth, to movement over or through the earth's surface, until it returns to the atmosphere through transpiration by vegetation or evaporation from land or water surfaces. The hydraulic engineer is concerned with only a portion of the hydrologic cycle, but his skills and knowledge are required in the field of hydrology, as are those of the meteorologist, the geologist, the climatologist, and others. The hydraulic engineer is engaged, for instance, in the measurement of streamflow, the determination of the movement of ground water through the soils and rocks, and in the transport of sediment by flowing water. The development of water supplies from wells or surface streams and the management of water projects therefore involve the hydraulic engineer to an important degree.

The development of irrigation has progressed during the past half century to an extent never before approached. One-fourth of the world's population not only lives on irrigated land but is almost exclusively fed and clothed by the products of the land. Man's existence in great numbers in arid lands, such as our own arid West, requires the practice of irrigation. In this country irrigation has been accomplished principally by diverting water from streams and rivers through canals and ditches to the land, although great strides have been made in the development of supplemental irrigation by sprinkling. The design of efficient and economical irrigation systems demands combined attention of highly skilled and experienced specialists, including the hydraulic engineer, the agronomist, the hydrologist, and others. Appreciation of the needs for careful design has come about through early experience with unsuccessful projects that resulted in financial ruin and human suffering. The practice of irrigation has brought about the specialized field of irrigation engineering, which combines the elements of the sciences specifically related to the problems of irrigation.

Floods have played an important role in the history of the human race. Because of the attractiveness of alluvial flood plains for agriculture and the proximity of the life-giving water of the rivers, man has often preferred to live in the river valleys. The convenience of water transportation has enhanced the attractiveness of river banks as places of abode. Occasionally the river which formed the rich flood plains and supplies its moisture returns to claim its own, with resulting destruction of life and property. In the case of the Yellow River, often called "China's Sorrow," occupants of the flood plain are periodically subjected to floods that bring death to thousands and loss of property and misery to millions.

In the United States and in other highly developed countries, great effort has been expended to reduce the effects of flooding. In this work, as in all problems involving moving water, the hydraulic engineer has made a contribution to human welfare. Efforts to control Mississippi River floods during the past 100 years have brought about extensive systems of levees, floodways, and upstream storage reservoirs that enable some 2,500,000 people to live in comparative security in the river valley. As an illustration of the magnitude of and current trends in the construction of flood control works in the United States, the Federal Government during the 80 years prior to 1936 spent about $400,000,000,

whereas during the 16 years between 1936 and 1952, appropriations directly related to flood control totaled about $3,500,000,000.

The hydraulic engineer has participated in many other ways toward the development of the physical aspects of our modern civilization, but it is beyond the scope of this discussion to elaborate further. The hydraulic turbines that drive the generators in the giant hydroelectric plants; the hydraulic pumps and long pipelines that transport oil and gasoline for hundreds of miles; the navigation canals, locks, and hydraulic dredges that facilitate water transportation, the sewer systems, water treatment plants, and storm drains of modern cities—all have required the use of hydraulics in their design.

The role of the civil engineer in hydraulics is therefore an important one, with many ramifications and interrelations with other engineering and scientific skills. Hydraulic problems have given rise to the recognized engineering specialty of hydraulic engineering. The hydraulic engineer is indeed a product of our civilization and at the same time a contributor to its development.

INTERSTELLAR MATTER

The vast distances between the stars—light from the star closest to the sun takes more than four years to reach the earth—are not entirely empty. In interstellar space there are enormous invisible clouds composed of gases and "grains," whose nature is completely unknown, out of which eventually new stars are born. Locating and defining these clouds and determining what they are made of remain some of the most pressing problems of modern astronomy, says Dr. Lyman Spitzer, Jr., of Princeton University, in a report in "New Horizons in Astronomy," recently published by the Smithsonian Institution, supported in part by the National Science Foundation.

At best, it is pointed out, interstellar matter is very finely dispersed. Space presumably is emptier than the finest vacuum ever achieved on earth. Even so, the total amount of matter in interstellar space is enormous, and these invisible clouds are the mothers of stars and star systems.

Two or three new techniques now promise for the first time to yield some information on the nature and distribution of this "mother stuff" of creation. Presumably it contains all the known elements. One method is the determination of minute color differences between stars, known to be of the same intrinsic type and luminosity, owing to the amount of matter through which the light passes. This will indicate directions in which the interstellar material is most abundant.

Another possibility, Dr. Spitzer's report points out, is determination of the nature of interstellar material by measuring much fainter differences in the spectra of light emitted by stars than has been possible in the past. Atoms of the various elements through which light passes absorb certain wave lengths. This is true for atoms of calcium, iron, and titanium, believed to be quite notable constituents of the clouds.

Probably the most prominent element of all is hydrogen. Under certain conditions, present in interstellar space, this gas emits specific radio waves. By means of the now rapidly developing science of radio astronomy it should be possible to determine the density of hydrogen in various parts of the heavens.

The nature of the "grains," out of which the stars are eventually formed, still defines the ingenuity of astronomers.

"We know," says Dr. Spitzer, "approximately the conditions under which atoms in interstellar space gather together to form solid particles. However, the nature of these particles is completely unknown. The detailed structure of the grains, the forces holding them together, and, in fact, all except the grossest properties of these small solid particles are completely uncertain. "The interactions of grains with atoms, including the rate at which the grains grow and are destroyed and the various selective ways in which they interact with different types of elements, are of particular interest astronomically."

The central problem, Dr. Spitzer points out, is that of the evolution of these grain clouds. From interstellar matter, perhaps equally dispersed, the vast interstar clouds form in periods of a billion years or more. Then, through unknown processes, the extremely tenuous clouds themselves in some way must condense to form the enormously hot, solid bodies of stars, sometimes with families of planets around them.

Something may be learned, he points out, about the "weather" of space—the origin of the turbulent movements in the gas clouds which presumably are necessary for condensation, the effects of radiation which they both emit and absorb, and the effects of cosmic rays passing through them.

The Role of the Civil Engineer in Irrigation

By F. E. Byrns (Bureau of Reclamation)

Irrigation, defined in the simplest terms as "the controlled application of water to arable lands to supply crop requirements not satisfied by rainfall," presents a major challenge to the civil engineering profession. This has been true for many centuries, although in the complexity of today's living, irrigation, not only in the United States but throughout all the world, no longer stands alone but is one of several major considerations which must be taken into account in multiple-purpose planning in the field of water resource conservation.

Thousands of years ago the development of civilization was begun almost simultaneously in several areas of the Near and Middle East. And the history of irrigation began with the history of man. In fact, some authorities claim that irrigation constituted the basis for civilization.

The climate in that part of the world was probably more humid then than now, but it was still too arid for the production of crops without supplemental water. As a result, civilization first developed in the valleys of the great rivers—the Nile, in Egypt; the Tigris and Euphrates, in what is now Iraq; and the mighty Indus and its tributaries, in West Pakistan.

Evidence exists that Nile River water was conveyed to adjoining arable lands as early as 5000 B. C., and prehistoric references indicate that King Menes, of the 1st Egyptian Dynasty, built a masonry dam across the Nile, near Memphis to divert water for irrigation, more than 3,000 years before the time of Christ.

Archeological excavations have revealed that irrigation was well developed in the Tigris and Euphrates Valleys in Babylon, and along the Indus River, during the same period. Hammurabi, a great king who consolidated the first Babylonian Empire, about 2100 B. C., to include the whole of Mesopotamia, is famous for a code of laws compiled during his reign and bearing his name. Included in the Code of Hammurabi are provisions dealing with the operation and maintenance of irrigation works, one of which, for example, reads: "If anyone opens his irrigation ditches to let in water, is careless and floods the field of his neighbor, he shall measure out grain to the latter in proportion to the yield of the neighboring field."

Although irrigation practices during those ancient eras were mostly of a primitive nature, explorations and records show that considerable skill and ingenuity were exercised in constructing irrigation works. The dam constructed across the Nile during the reign of Menes is an example.

A great number of ancient irrigation developments were to a certain extent multipurpose in character, such as the Shahpour barrage, built probably in the third century A. D., across the Karoun, in Iran, where the 30-foot drop was used to operate water wheels to provide power for grinding meal, and another substantial masonry barrage built at Esfhan, Iran, in the sixteenth century A. D., which in addition to serving as a diversion structure also supported a roadway which was an important link in the overland communication system of the country. Many such structures are still in use in the Near East today.

At the time of the Spanish conquests in the western hemisphere, extensive and well-built irrigation systems existed, antedating the earliest traditions of the peoples using them. Traces of such works are found not only in South and Central America, but also in southern Arizona, New Mexico, and California.

The modern era of irrigation in the United States is usually dated from the settlement of the Mormons near Salt Lake City in 1847. During the balance of the nineteenth century, many irrigation projects were developed throughout the West, principally as private or cooperative enterprises, organized under State laws. Most of the projects were relatively small but some included areas of many thousands of acres. Many of the smaller projects were planned and built by the water users, without engineering assistance. Civil engineers in private practice

planned and supervised construction of many of the larger projects. All, however, were the simpler, easier to design and construct, single-purpose irrigation projects.

After the passage of the Reclamation Act in 1902, the United States Bureau of Reclamation began developing new projects of considerable size and increasing complexity. For many years, the Bureau's organization was almost exclusively an organization of civil engineers, whose functions included all phases of investigations and surveys, planning, designing structures and other features, construction, and operation and maintenance of extensive irrigation works.

These activities encompass practically all branches or divisions of civil engineering, including topographical and geodetic surveying, geology, hydrology, hydraulics, and the design and construction of storage and diversion dams, with spillways and outlet works, scouring sluices, fish ladders, and logways, power plants, pumping plants, tunnels, flumes, and siphons, canals and laterals, pipelines, canal structures, such as headgates, turnouts, spillways, checks, drops, and chutes, water measurement weirs or boxes, roads, bridges, housing, including water supply and sewage disposal systems, and many other structures and features, of both major and minor importance. On some lands, drainage systems must be provided to prevent or relieve waterlogged conditions.

With the exhaustion of the "easy" project possibilities which were based upon the gravity distribution of natural streamflows or diversions from single-purpose storage, our engineers advanced to the multiple-purpose project involving storage and distribution of irrigation water through gravity and pumping systems, coupled with the development of hydroelectric power, flood control, provision of municipal water supplies, assistance to navigation, and other supplemental benefits to recreation and to fish and wildlife conservation.

To handle these multiple-purpose developments, other engineering professions, particularly mechanical and electrical, have become participants in the broad field of reclamation.

The civil engineers of the United States Bureau of Reclamation have conceived and carried to fruition projects which were beyond imagination only a few decades ago. Highlights of their activities include Hoover Dam of the Boulder Canyon Project, the highest dam in the world, which created a reservoir of 31-million acre-feet capacity, the world's largest artificial body of water; Grand Coulee Dam, the world's mightiest concrete structure, containing more than 10 million cubic yards of concrete, and with a spillway twice as high as Niagara; and the Alva B. Adams Tunnel, punched through the Continental Divide to divert water from the Pacific Ocean watershed to the Atlantic Ocean watershed.

In October 1955 a special committee of eminent members of the American Society of Civil Engineers, after three years of deliberations, and consideration of more than 200 modern achievements of civil engineering, with the concurrence of the Society's Board of Direction, designated the "Seven Modern Civil Engineering Wonders of the United States." Criteria set by the special committee included service to the well-being of people and communities, pioneering effort in design and construction, uniqueness, beauty, size, and, in some instances, extent to which a project has been copied successfully.

A significant feature of this selection is that two of the seven "wonders" were the Hoover Dam in Arizona-Nevada, and the Grand Coulee Dam and Columbia River Basin Project, Washington. A third of the seven wonders was the Colorado River Aqueduct, a related water-resource development project designed and constructed by the same engineering organization.

We have progressed a long way from the simple diversion of natural streamflow onto adjoining acres of arable land. But the challenge of the past is also a challenge of the future. We now realize that the ultimate objective of any water development scheme is the permanent improvement of social and economic conditions in a particular area. Major water development schemes should be based on comprehensive general plans for the final, optimum utilization of all water and land resources within the river basins under consideration.

And this challenge of the future is not confined to any one country—it is world

wide. Every night, one-half of the world's people go to bed hungry—every morning there are 80,000 new mouths to feed, the excess of births over deaths during the preceding 24 hours. And while these mouths cry out for food, there still remain millions of acres of fertile land that are now sterile for lack of fresh water, which is wasting unused to the sea, that could help to feed a hungry world.

To meet the demands of the world's steadily increasing population for more and more food for existence alone, and then for the production of more hydroelectric power, and for other developments to provide a better standard of living throughout the world, we will eventually need to put every last drop of water to work, through conception, planning, design, construction, and finally operation and maintenance of ever larger and more complicated irrigation and multiple-purpose projects.

To meet this challenge, we will need to draw upon nearly all branches of science. But in the future, as in the past, the leading role must be assumed by the civil engineering profession.

RADIO STARS

The hundreds of invisible "radio stars"—points in the sky from which our radio telescopes receive signals but where our optical telescopes usually can reveal nothing—in many cases are probably enormous, highly turbulent masses of gas whose atoms have been highly ionized, or stripped of their outer electrons. This is the conclusion of Drs. B. F. Burke and Merle A. Tuve, of the Carnegie Institution of Washington, based on study of the one known feature possessed in common by the handful of radio sources which are also visible to the optical telescope. The report has recently been published in a symposium on "New Horizons in Astronomy" by the Smithsonian Institution.

It is highly probable, however, that various conditions may result in producing a "radio star." It appears certain that the necessary highly turbulent gas can be produced in a variety of ways. In our own galaxy, cataclysms such as the birth of a supernova (an explosion in which a star attains millions of times its ordinary brightness for a brief time and then fades to near invisibility) are known means of producing a turbulent medium capable of strong radio emission. Many discrete radio sources may possibly be remnants of supernovae. Many of them may also represent an entirely new class of objects. One of the best known of the visible radio sources is the Crab Nebula, now known to be the remnant of the historically recorded appearance of a supernova.

Burke and Tuve say that there are also radio signals from objects outside the Milky Way galaxy, millions of light years distant. Some of these signals are as strong as those known to originate within our own galaxy. They must require an origin even more violent than that of a supernova, the report says. In one case, the source in Cygnus, they are known to result from the collision, still in progress, of two galaxies, aggregations of hundreds of billions of stars embedded in gas and dust. It is possible that some other extragalactic radio sources are due to the same cause but, the Carnegie astronomers say, there are some galaxies from which signals are received which apparently do not fit this picture.

As there are at least two different populations of radio sources, they say, it is important to distinguish between them and to establish, if possible, a distance scale. The only reliable method at present seems to be the identification of the radio source with some visible object, but as time goes on this must prove increasingly difficult. Even now it is known that if a pair of galaxies were colliding as violently as those in the Cygnus source (the one positively identified), but were ten times farther away from the earth, we would have little hope of observing it visually in our telescopes.

Similarly, many galactic objects, conspicuous in the radio region, are undoubtedly so obscured by dust that optical observation will be difficult. A distance scale for radio sources would certainly bring to light interesting new problems. Distribution in space of extragalactic radio sources may provide a clue to important cosmological problems, since it is probable that many observable sources are situated at great distances, approaching the limits of the visible universe.

There now is a wide discrepancy, they point out, in the opinions astronomers hold about the distribution of radio stars. This difference is due largely to different methods of observation. A survey carried out at Cambridge University in England, for instance, indicates the existence of a very great number of faint sources, whose number apparently increases with distance. A survey by Australian observers, on the other hand, indicates that radio sources are about equally distributed in every direction throughout space.

The Role of the Civil Engineer in Soil Mechanics

By Edward S. Barber (University of Maryland)

Soil mechanics, which encompasses the physics, chemistry, and even biology of aggregations of particles as applied to civil engineering, is beginning to be called soil engineering. The core of soil mechanics is a study of the strength and volume change of soil under various water conditions applied to the design and construction of airports, dams, tunnels, highways, and foundations for bridges and buildings. It also includes studies of soil shrinkage caused by trees, the drainage of water by electric currents, and the chemical stabilization of invasion beaches.

EXPLORATION

Since civil-engineering structures rest on or in the earth, the natural state of soil is of prime importance to the soil engineer. Even if the soil is to be disturbed for an embankment, the method of excavation and selection of materials must be planned. The basic method of exploration is by sampling from holes drilled or dug in the ground. It is necessary to locate such holes economically and to project the data obtained from sampling to indicate the conditions between the holes. Geologic information is used for this purpose. Particularly in the field of exploration, there is a mutual interest between geologists and soil engineers. Near Washington it is often possible to estimate the depth to firm red clay from geologic maps, and when this layer is found in borings assurance is given that there are no soft river deposits below.

The soil engineer also employs geophysical methods of exploration: particularly seismic, in which vibragraphs measure the time of refraction of impulses from a charge of dynamite; and resistivity, in which the subsurface conditions are inferred from characteristics of an electric field applied at the surface of the ground. Seismic methods were used to outline rock foundations at the Carderock Model Testing Basin. Resistivity was used to outline the buried silt between runways at the Washington National Airport, and has been widely used to locate gravel for construction.

Results of agricultural soil surveys are also used to correlate data on an areal basis, particularly for highway location and preliminary design. Aerial photographs, which are now generally available, can similarly be used; for instance, sand and gravel are indicated by lack of surface drainage. In military operations, air photos may be the only source of soil information to determine trafficability of inaccessible terrain. Several organizations are working on the development of engineering soil maps based on data from all these sources. It is not always possible to locate roads where the best conditions exist. Thus it is said that, due to right-of-way costs, new road locations in New York are evident on a geologic map—they will follow the marshy ground and river flood plains.

Old maps are often valuable in showing previous conditions which may have been obliterated by natural or artificial filling. This is particularly true around Washington where a large part of the park areas were reclaimed from the river. However, higher areas are also involved. For instance, buried marshy deposits at the proposed site of the General Accounting Office were found by careful exploration although inadequate preliminary borings were confined to the upper layer of gravelly fill. A map, showing even the intermittent streams between Florida Avenue and the District Line, which was prepared by the Coast and Geodetic Survey 70 years ago, is still in print. Others are available at the Library of Congress. However, it is always necessary to be cautious in the use of these old maps—in one case, where present and old contours agreed, borings showed that the original clay had been removed (for brickmaking) and replaced with rubbish fill.

While field loading tests are sometimes made and the observation of completed structures is necessary for the corroboration of designs, questionable soils are evaluated

by laboratory tests made on undisturbed samples. It is not possible to obtain completely undisturbed samples since the stresses are changed by any method of reaching the point of sampling. However, much effort and care are employed to obtain samples in their natural condition, since their properties reflect the history of formation and cannot be artificially reproduced. Leached marine deposits are often extremely sensitive to disturbance.

The basic structural tests determine the permeability, volume change with load or moisture variation, and the shearing strength corresponding to various depths and opportunites for drainage.

FOUNDATIONS

The shear test is used to determine the size and depth of footings required to carry a given load, as for a building or bridge. For bridges over water the depth of footing is also controlled by possible scouring away of material during flood flows. Although inspections after flood always showed mud over the footings of the Pennsylvania Railroad Bridge crossing the Anacostia River, a pier was lost during a flood which removed the mud and took gravel from under the footings. Since the mud was replaced by the subsiding floodflow, the necessity of measuring scour during a flood was demonstrated. Piles of wood, steel or concrete may be driven to carry the load to greater depths. Much study is given to their bearing capacity since the more apparent dynamic resistance to driving may be quite different from the resistance to static load.

The weight of fill on soft approaches to bridges tends to push the abutments together. It was necessary to cut one foot off of the bascule span of the Eleventh Street Bridge over the Anacostia River before soil engineers were available to warn against the probability of such movement.

Approach fills over soft ground also cause abutments to settle due to squeezing the water from the subsoil. Such a condition made necessary the underpinning of the north abutment of the new Fourteenth Street Highway Bridge over the Potomac River. There was no soil engineer on the job to warn of this because it was not recognized that such a problem existed. Settlement of a nearby structure was not recognized because it was used for a bench mark and bench marks are not supposed to settle. On the basis of consolidation theory and volume change tests, the future settlement of the abutment could have been predicted. The pattern is similar to the continuing settlement of the Washington Monument caused by densification of a deep silt layer. Similar predictions were used to adjust new foundations to the old shell in reconstructing the White House.

The soil engineer has a problem of revising sometimes faulty older methods, without relying too much on untried methods which may be impractical even though theoretically correct.

Injection of chemicals has been required to stop settlement of foundations on sand subject to vibration. Vibrating compactors have been developed to densify such sands, including one that will sink itself as much as 100 feet into loose sand and compact the same as it is withdrawn.

WALLS AND TUNNELS

An old theory of earth pressures was widely used to calculate pressures on walls because it gave answers without having to consider the type or rigidity of support. Soil mechanics now recognizes the importance of the support and thereby explains the different pressures on retaining walls, trench sheetings, culverts and tunnels. Owing to stratification and jointing, rock formations are often an aggregation of large pieces and its properties can be studied by an extension of soil mechanics. Soil engineers were employed to evaluate the rock to be penetrated by a new Washington Aqueduct as well as predicting the lateral and uplift pressures on various underpasses. The soft sediments in the buried Susquehanna River channel were carefully tested to evaluate the possibilities of a tunnel as an alternate to the Chesapeake Bay Bridge.

SLOPES AND DRAINAGE

While landslides are particularly a problem in mountainous areas, they can be a problem wherever too steep a cut is made in

the soil. Failures of cut slopes are usually caused by water. A typical condition around Washington is sliding in clay overlaid by gravel which supplies the water. Such slopes can be stabilized by drilling almost horizontal holes from the face to intercept the water; a hydrauger has been developed for this purpose. Stability of a housing development in Anacostia was improved by drainage of groundwater. A critical slope on the Ohio Turnpike was drained at considerable cost to give even a minimum assurance of future stability.

Vertical sand drains are used in soft foundations to aid the escape of water squeezed from the soil under fill construction. Many miles of such drains made possible the construction of the New Jersey Turnpike through the Jersey Meadows which could not previously carry a man without displacement. To control the rate of loading the foundation, displacement and internal water pressures are measured continuously. Thin seams of undrained material can cause instability. After a failure at Fort Peck Dam, caused by layers of clay missed in samples from borings, a camera was developed to take a continuous picture of the side of bore holes.

Drains are also used under dams for a different purpose. Uncontrolled seepage has caused many failures by progressive erosion or piping from a downstream outlet. By constructing drains under the downstream slope, seepage is carried safely away while the soil is held in place by filters of properly graded sand. This principle of sand filters has been applied to subsoil drains for highways and airports to prevent failure of the drains from infiltration of soil into the coarse stone backfill previously used. (The architectural profession has not generally applied this principle.) A layer of sand under macadam bases for pavement has prevented failure caused by upward intrusion of soil softened by water infiltration. More recently granular bases are being placed under concrete pavements to prevent trucks from pumping the subgrade soil up through the joints, cracks, and from beneath the pavement edges.

HIGHWAYS AND AIRPORTS

Not many years ago, new fills were considered unsafe for bearing and were left to cure for several years. While a neighboring city waited ten years in vain for a fill of river silt to become stable, the runways of the Washington National Airport were placed on selected sand and gravel pumped from the Potomac River.

By placing soil in layers, adjusting the moisture to the optimum and thoroughly compacting with the proper roller, fills can be made better than most natural soil and can be used immediately. New fills have been used to build dams over 300 feet high, as bases for smooth super-highways, and to support building floors and even entire housing developments. The extension of the Navy Building in Arlington is on such a fill. While fills can now be made satisfactorily, this does not make uncontrolled fills satisfactory, as attested by the cracking in ground floors of many local buildings. The practice of building codes to assign an arbitrary low bearing capacity to fills is poor—a fill may be worthless or it may provide excellent support. Soil Mechanics affords a means for its evaluation.

While compaction is basic to stabilization of all granular materials, the upper layers of pavements require closely controlled gradation or special stabilization treatment. Lacking sufficient coarse material, cement and soil may be mixed to make a good base course (despite the fact that concrete specifications require that aggregate be free from soil). Stiff bituminous materials may also be used to stabilize certain natural sands. In searching for a cheap method of stabilizing soils for low cost road surfaces, many methods and materials have been tried—such as lime and molasses in India, burning in Australia, electric fusion in Russia, paper manufacturing wastes in the Northwest, pine rosins in the Southeast, lime in Texas, and lime and fly ash in the Eastern United States. The Armed Forces, interested in expediency rather than cost, are experimenting with all these, plus many others, including plastics. Some of the newer methods are being used to improve the ancient processes of making building walls of earth.

Because of the great activity of clay and the high strength available when moisture is limited, it may be possible for small amounts of admixture to have a remarkable effect on a clay soil. To study the how and why, considerable basic research is being done on clay minerals by means of x-ray analysis, differential thermal analysis, determination of surface area and base exchange investigations. Electron microscopy shows the clay minerals to be crystalline flakes, tubes or lathes contrasted to other soil components, such as: amorphous iron oxides, silica, lime or organic matter; fragmented shells or coral; porous pumice or diatoms; flaky mica; and sand or gravel in various stages of rounding.

The failure of many earth roads immediately after improvement with a bituminous wearing surface led to specifications requiring less clay in base courses than in surface courses. Much study is being given to the accumulation of water under pavements. In arid regions the only green grass is often alongside the pavement.

Drainage is essential to prevent weakening by the quick-sand effect when water is forced upward, either from underground pressure or the rapid application of surface loads. In some cases, water is forced up through the pavement as solar heat reaches through the pavement and expands entrapped air. In other cases, discharge from subdrains is found to be controlled by temperature so that they may drain in dry weather and fail to discharge after a rain.

FROST

In the Northern States, pavement foundations are designed against frost effects. During freezing, water tends to accumulate in lenses of ice, causing heaves; when this ice thaws in the spring, the load carrying capacity of the pavement is greatly reduced. Where this is an annual occurrence, soil engineers have learned to take care of it by selection of materials and drainage. States where deep frost is only occasional, sometimes suffer most damage due to lack of preparedness.

In the far North, where the ground is permanently frozen, special construction is required to prevent melting of permafrost due to removing the natural insulation, or from heat supplied by structures.

Cold storage rooms next to the ground can cause frost heave; heating cables placed in the ground may be used instead of an excessive thickness of insulation.

WETTING AND DRYING

When clays dry, they shrink, and when rewetted, they rebound or swell. Thus foundations on clay must be placed several feet below the ground surface. When there is an intense dry season, this depth may be as much as 10 feet. A church floor built on dry clay in Texas was lifted 12 inches as the clay absorbed water during the rainy season. Many shallow footings around Washington have been subject to such movement. When drying is accelerated by growing trees, the solution may be simply to remove the trees. Basement heating plants also cause drying. It has been found necessary to separate brick kilns from clay subsoil. In testing the durability of stabilized soils, alternate wetting and drying is often more destructive than freezing and thawing.

CLOSING

The soil engineer uses information from many nonengineering fields: particularly capillary moisture data from agricultural soil physics, clay technology from ceramics, sand stability from foundry practice, sedimentary petrography and groundwater data from geology. Conversely, data from soil engineering occasionally serves others, such as helping sedimentologists estimate the rate of consolidation of silt in Lake Mead or indicating the required size for grinding commercial fertilizer components to prevent segregation. Soil engineer ng is beginning to be applied to the mobility of construction and transportation equipment. It has much in common with the new science of snow and ice mechanics and is closely related to the fields of soil conservation and the maintenance of shores and harbors.

Soil engineering as an applied science is relatively young, and is still developing, particularly in the realm of field observation. While much theory is available, soil engineering is the art of applying science to actual soil situations.

The Role of the Civil Engineer in Highways

James O. Granum (Automotive Safety Foundation)

The greatest engineering program in history—new construction of 40,000 miles of modern freeways throughout the United States—is bringing the civil engineer to new peaks of prominence in civilization. More than ever before, civil engineers trained in highway research, planning, construction and operation have great responsibilities to meet in shaping the face of the nation.

New Federal legislation calls for a 13-year building program on the National System of Interstate and Defense Highways costing $27 billion. The legislation also is sparking expanded state and local highway construction. All together, it is estimated that some $9 billion annually for many years, will be spent on the nation's highways, roads and streets. Furthermore, this precedent encourages a world-wide step-up in highway development.

Today the civil engineer specializing in highways has the most challenging opportunities of the entire profession. Motor vehicle transportation in the Unites States has doubled in the past decade; is expected to double again by 1975. Economic growth of the nation and, perhaps, even peace in the world, depends on motor vehicles and the highways which serve them. New patterns of living, new forms of industrial and business operations, new development of agriculture and natural resources—all are made possible by flexible, speedy, efficient, individualized motor transport.

But this surging growth of vehicle use has multiplied new and old problems on a grandiose scale. Importantly among these problems are city congestion and suburban growth. One of the gravest is that each year some 40,000 deaths and more than 1,350,000 injuries occur on the nation's 3,300,000 miles of roads and streets. Cost of these accidents is estimated at $4.5 billion annually. Decisions and actions by highway engineers directly affect the lives and welfare of all citizens.

New concepts of highway planning and design are being developed by civil engineers everywhere. No longer is the highway engineer content with a transit or a slump cone. Now his tools include aerial photography, electronic computers, complex laboratory and field research methods and testing devices, new statistical procedures, visual aids and a host of other modern techniques.

Those tools help to get the facts about how highways are used—when and where people and goods are going and how; numbers, types, weights and speeds of vehicles—and costs and benefits of various highway locations and designs. Geologic and soils studies, materials research and new methods of construction and maintenance produce better roads for the users.

RESEARCH

Basic research is more vital to highway development than ever before. As in all branches of engineering and science, highway location, design, construction and maintenance depend on research. Experience and judgment are major elements—but these are only names for accumulated observation of fact from which certain conclusions may be drawn, i.e.—research, albeit somewhat less formalized than usually thought of in that connection.

Highway engineers, increasingly aided by disciplines of mathematics, physics, economics, sociology, and others, rely more and more on detailed studies about the demand for highway service. It seems axiomatic that the purposes for which highways are built and maintained should dictate their location and character. Too often in the past, the engineer's facts, knowledge and judgment were insufficient to combat ill-advised political decisions, or were inadequate to lead to the soundest conclusions—especially in the face of continual demands to do more with less.

Now, 50 years of experience with motor vehicles give background and trends which can be projected with reasonable certainty to afford a basis for location and design.

Highway engineers have pioneered the research jobs required. Among them are:

Traffic volume—location and time
Traffic characteristics—speed, size, driver behavior
Highway capacity—ability to carry traffic
Origin and destination—travel desires
Safety—causes and cures of highway accidents
Urban planning—inter-relations affecting transportation
Economic analysis—cost vs. benefits

Research activities continue to be accelerated in a wide variety of investigations of soils, materials and methods of construction, design of structures, pavements, grading and drainage, maintenance, traffic operations, and administration.

Research is carried out by universities and colleges, public highway building agencies, private organizations, material and equipment suppliers, and builders. The Highway Research Board, a division of the National Research Council of the National Academy of Sciences, helps to initiate and coordinate all such research on a national basis.

PLANNING AND DESIGN

The planning and design of highways, roads, and streets gives widespread opportunities to the civil engineer to achieve the ultimate goal of his training—the fine balance needed to meet the demands for service at the lowest annual cost.

Here the engineer's knowledge of highway maintenance and construction problems and costs must be related to driver behavior, operational characteristics of his designs and the economic and social benefits of his product. The tremendous complexities of modern transportation, and the infinite variety of human reactions toward development and use of highways, place great responsibilities on the planning and design engineer. One example demonstrates the scope of his problem.

The Congress Street Superhighway in Chicago cost $100 million for 8 miles. It involved moving 13,000 people and 450 commercial and industrial firms and razing buildings of up to 12 stories. The new facility will carry more than 100,000 vehicles daily—without traffic signals and at speeds of 50 miles per hour. It will tremendously enhance property values in its corridor, and beyond. It will cut accidents to a fourth of those on the former route. It will change the character of the city and living patterns of people, as it becomes interconnected with a growing network of similar highways. Balanced against those benefits, the actual cost of the highway and its maintenance will be not more than a half cent per vehicle-mile—only a sixth of that required for a "low-cost" farm road.

The engineering required for all types of highway improvement calls for many related engineering assignments. Mapping, reconnaissance, route location, preparation of surveys and plans and estimates of cost, together with alternate route studies, economic analyses and determination of priorities and programs, involve the highest of civil engineering skills. And Herbert Hoover's basic engineering question, "Not *what* to build, but whether to build at all," guides the initial decisions.

Aerial photographs, topographic maps of the U. S. Coast and Geodetic Survey and special maps and surveys by the highway agencies themselves provide the basis for location studies. Through the science of photogrammetry, it becomes possible to locate new facilities within quite accurate limits. Then, by means of new electronic computers, survey computations and balancing of earthwork for various profiles and lines can be done quickly and easily. On-site inspections and studies finally must confirm initial studies and develop details of design.

The civil engineer who specializes in structural design finds the widest variety of opportunities in highway work. His ability is challenged not only by great bridges like the San Francisco Bay Bridge; the $100 million Mackinac Straits span linking the two peninsulas of Michigan; the 24-mile Lake Pontchartrain bridge near New Orleans; and the 12-lane, double-deck, $220-million Narrows Bridge to be built joining Brooklyn and Staten Island, but by hundreds of thousands of lesser spans. Today, increasingly complicated freeways demand thousands of new structures and spaghetti-like interchanges for channeling traffic over, under, around and through modern facilities.

Some urban freeways are almost continuous lengths of multi-level structures. Tunnels through mountains and buildings are not uncommon. The toughest problems, however, lie ahead as engineers tackle the job of pushing through whole cities with superhighways.

CONSTRUCTION, MAINTENANCE, AND OPERATION

Action is the hallmark of the civil engineer —the builder. The construction phases of highway engineering are the visible evidences of accomplishment which attract the active mind to create new methods—to do better work in less time at lower costs.

Translation of paper plans to concrete, macadam and steel—on rock, shifting ground, over vast reaches of land and water, through cities, mountains and desert —stirs the imagination and ability of all men.

The civil engineer controls this vast development of highways. He lays out the work on the ground, he inspects the production, he checks soil conditions, materials and methods and meets the unexpected with on-the-spot decisions.

Increasingly, material and equipment producers use civil engineers to study their products in action, to develop new and improved materials and machines, to devise new uses and to aid engineers and builders in their problems of design, construction, and maintenance.

Contractors, too, are finding it profitable to use more civil engineers in their construction operations. Through the engineers' knowledge of fundamental principles and their basic training, better management of work often is secured, improved cooperation is possible and superior work is done.

Engineers are responsible for nearly $2 billion worth of maintenance work carried out annually on the road and street systems of the nation. This generally is done by forces under direct supervision of the engineer who can exercise his talents for management and ingenuity to the freest extent in maintenance work. Although seemingly prosaic, the importance of keeping highways, roads, streets and bridges in safe operating condition for all kinds of weather and traffic is a major function of highway departments. Floods often do terrific damage, snow and ice clog the arteries of transportation, and emergencies (like landslides and their prevention) demand the best organization, efficiency, plans, equipment and knowledge of the engineer. Keeping the roads open may mean life instead of death for many people, as well as confidence that "business-as-usual" can be maintained under all conditions.

Operation of highways for ease and safety of travel is another major field for civil engineers. Traffic control, regulation, routing and protection are acknowledged as basic engineering problems which recognize, more than some other phases of highway work, the human element in drivers' use of highway facilities.

People must be guided to where they want to go; speeds must be regulated in keeping with highway design and drivers' abilities. Safe operation requires protective devices such as signals, stop signs and lane markings. Smooth, fast flow of traffic can be aided by schemes such as channeling vehicles on one-way streets. The best ways of doing these things are determined by engineers specializing in traffic engineering. In carrying out their objectives, they work in cooperation with designers, police, psychologists and others.

EDUCATION

In the face of expanding highway needs and programs, the supply of civil engineers specializing in highways has continued to decline, resulting in great demands for their services.

This puts emphasis on making best use of trained engineers and providing them with all modern aids to increase productivity. Technicians, as in the medical profession, are replacing engineers in many routine ways, and electronic machines and other methods save time and talent. But there remains great and continuing need for training of technicians and for undergraduate and postgraduate civil-engineering education, with more emphasis on highway fundamentals. Thus one of the major roles for the civil engineer is teaching.

Today, universities and colleges offer many opportunities for engineering educators. Civil engineering courses are being increased in scope, with numerous highway and allied subjects offered. Graduate studies are being expanded, with special institutes of transportation engineering gaining prominence. Cooperative research, as well as instruction, is growing. At the same time, highway departments and educational institutions are expanding in-service training programs and short courses—all of which call for the knowledge and guidance of the highway engineer.

OPPORTUNITIES

The civil engineer in highways actually has been thrust into a dual role—he also wears the hat of a transportation specialist, a responsibility with dynamic facets and unlimited opportunities on a world-wide scale.

All agencies of government everywhere—Federal, state, county, city and regional bodies—are calling for the best engineering brains to study, plan, construct, maintain and operate what has become—with the exception of education—the largest single function of government.

To accomplish such a tremendous task involves the civil engineer in many allied functions. Teaching and research are basic. Private consulting engineers do much specialized planning, design and supervision. Material and equipment manufacturers and builders require engineering services on an increasing scale.

All this requires the highest degree of administrative skill in coordinating the development of billions of dollars worth of transportation facilities. This brings major financing, accounting, personnel, and public-relations problems into close relation with the engineering problems. So the civil engineer's role in highways has expanded also into the field of big business administration.

Through the teamwork of the civil-engineering profession, the greatest job in history will be carried out for the benefit of man for generations to come.

Advances in knowledge are not commonly made without the previous exercise of some boldness and licence in guessing.—W. WHEWELL

The Role of the Civil Engineer in Structures

By John G. Shope (National Lumber Manufacturing Association)

Before attempting to describe the role of the civil engineer in structures it would be well to define the term "structure." According to Webster, a structure is "something constructed or built as a building, a dam, a bridge." This definition is very broad and reflects the wide range of activities required by the civil engineer in the design and development of such constructions.

Reference to the civil engineer in this discussion is intended to include the structural engineer for the reason that structural engineering is generally considered a branch of civil engineering. The Structural Division is one of the departments of the American Society of Civil Engineers.

Generally speaking, the design of a structure is controlled by the requirements for use and space, structural adequacy and esthetics in those instances where the latter is a factor. Many structures such as radio transmitting towers are essentially problems of structural design where esthetics are of little little concern and wherein the major work in design is performed by the civil engineer. Other structures such as churches require thorough knowledge of the need and arrangement of space and a fine sense of esthetics, and in these structures the major role is carried out by the architect with the assistance of the civil engineer. The large volume of work in structures lies in the construction of buildings wherein the civil engineer works as part of a team with the architect in cooperation with those other branches of design concerned with mechanical and electrical equipment.

The role of the civil engineer in structures is concerned primarily with structural adequacy and this is an important factor in all types of structures. Structural adequacy means that a bridge is strong enough to carry the traffic for which it was designed. It means that a tower will not blow over when exposed to high winds. It means that a building will not collapse and endanger the lives of the occupants. The structures just mentioned do not stand up because of some unknown reason. They stand up because the anticipated load requirements were carefully analyzed and the structural elements designed to withstand these loads. This work is the responsibility of the civil engineer. In some cases the courts have held engineers financially responsible for structural failures due to errors in design.

The correct structural design must be economical if the civil engineer is to justify his position in the design of a structure. This means that the construction material selected must be used to its fullest advantage consistent with the arrangement of space required in the structure.

All structures require some form of foundation which must be designed to meet local soil conditions. It is needless to say that a building without adequate foundations cannot be expected to remain stable when the anticipated loads are applied. It is the job of the civil engineer to design foundations so that they will be adequate.

The bearing value of soil depends on the type of material and may vary all the way from 1½ tons per square foot for soft clay to 100 tons per square foot for bed rock. Before foundation design can be started the type of soil must be investigated, sometimes through borings and sometimes by test pits. The results will determine the type of foundation to be used.

Where hard soil is easily reached spread footings of plain or reinforced concrete are the customary method. Where such condition does not prevail piles of concrete, steel or wood are driven to bed rock or to such depth that the friction between the soil and the pile will develop the required load. Spread footings and piles represent the bulk of foundation work but other types including caissons and floating mats are installed under unusually bad conditions.

Obviously, the height of a structure and the loads to be applied to it have great bearing on the foundation design. Foundations for one-story buildings on reasonably good soil do not present much of a problem but foundations for tall office buildings in the central areas of cities are usually major works of engineering. Buildings of fifty or more stories with several basements and

sub-basements to be fitted in between subway tunnels, sewage, water, gas and electric lines represent puzzles which are bound to confuse the layman and which only the best informed civil engineer can solve.

The loads which structures must be able to withstand fall into two broad categories, the dead load of materials in the structure and the live loads applied to the structure both internally and externally. Dead loads are not difficult to determine since that is a matter of adding up the weights of the materials in the structure or any of its parts. Live loads, on the other hand, must be anticipated over the life of the structure. For bridges the movement of vehicles creates live load. For buildings the installation of equipment, merchandise, furniture, vehicles, and other contents and the occupancy by people all create live loads. Wind and sometimes earthquake represent external live loads which must be provided for. It is the job of the civil engineer to make certain that all of the loads which can reasonably be expected to come on the structure will be recognized in the design.

In designing a structure the civil engineer does not start from scratch in matters relating to design procedures, loads and working stresses for materials. He makes use of design procedures and of codes and standards which have been developed by technical committees of national organizations over many years. These committees include broad representation by civil engineers. The standards they develop reflect the results of laboratory testing, the running of full-scale tests in the field as well as recording the behavior of many buildings and structures.

The recurrence of earthquakes in California has resulted in detailed study of the behavior of structures under such conditions. Design procedures have been developed to the end that modern structures can be built to withstand such forces. This has produced great reduction in loss of life and damage to property. It represents an outstanding contribution to safer buildings on the part of the civil engineering profession.

The forces produced by vehicles moving across bridges has received much study by engineering committees of railroads and by similar committees representing highway departments. As the result standardized methods for recognizing the effects of moving loads are used and contribute to simplification of design procedures.

For buildings many studies have been made to determine the magnitude of live loads which should be anticipated on floors due to contents and people. These are set forth in building codes and serve as the basis for design for structural adequacy of the various floors and supporting members. Such loads range all of the way from forty pounds per square foot for residence buildings up to 600 pounds per square foot for foundries.

The effect of wind on buildings and other structures likewise has received much study and here also design requirements are set forth in building codes. The civil engineer must recognize the increase in wind pressure with the increase in height of the building and also the fact that the vacuum created on the leeward side of a roof may be more intense than the pressure on the windward side. Some years ago a suspension bridge in the state of Washington collapsed during a wind storm and it was later determined that collapse was due to harmonic motion induced by the wind. This phenomenon resulted in considerable study directed toward more lateral stability for such structures.

Structural building materials of all types must be used within the safe limits, or the working stresses assigned to them. The assignment of working stresses for any material is a complicated procedure which involves much laboratory testing followed by careful analysis of the results by competent engineers. Following this, factors of judgment (or factors of safety) are introduced and the allowable working stress assigned. Obviously, working stresses can be assigned only on the assumption that there will be some control of the quality of the building material. To assure this quality control some form of identification is required by the consumer. Also, there must be reasonable assurance that the material will continue to perform satisfactorily over the anticipated life of the structure. Working stresses for all structural materials are set forth in building codes and other standards for structures not covered by codes. These serve the civil engineer in executing his design.

The discussion up to this point has been devoted to matters relating to the design of

structures. Of necessity it has been very brief and in no way is intended to imply that problems of design are equally brief or easy. On the contrary, many of them are very complicated, each requiring the services of a substantial staff of engineers. Any one of these design problems could be the subject of a detailed technical paper. Many such papers have been printed and those who are interested may find them printed in Civil Engineering, monthly journal of the American Society of Civil Engineers and still more details in the Journal of the Structural Division of ASCE.

Those who have seen a surveyor waving his arms at the site of a bridge or building know that the engineer's work does not end on the drafting board. There are many who think that it has just begun. For one thing the structure must be placed in the right location and at the proper elevation and this is one of the early jobs of the man with the transit or level. As the work progresses he also provides direction in the location of main supporting structural members. All field erection work must be within close tolerances, otherwise prefabricated assemblies prepared in a shop many miles distant would not go together or fit in with other parts of the building.

The erection of a structure involves many engineering problems relating to safety. The public can be excluded from hazard by construction of a fence or other barrier but workmen at the site are constantly exposed to hazards of many types. Excavations must be shored to prevent caveins. Hoisting devices must be strong enough to carry anticipated loads. Temporary field connections of the various structural elements must be adequate and lateral bracing installed where needed. Lifting a trussed member into place may result in reversal of stress to the end that a member designed for tension would be placed in compression. This means that the truss must be designed to withstand erection stresses as well as those which will be induced through use of the truss after it is in permanent place in the structure.

The various instances of collapse of formwork under freshly poured concrete frequently with the loss of one or more workmen demonstrate the need for careful engineering analysis of such formwork before the load is applied. When new concrete starts to move there is not much that can be done except to get out of the way, if that is possible. One common error in formwork is to overload the vertical members by not installing enough lateral bracing. This bracing serves to reduce the ratio of unsupported length to thickness and thus increases the load carrying capacity of the post. Because of the potential hazard, all formwork of any consequence should be inspected by a civil engineer before concrete is placed. Such inspection could eliminate substantial loss to the builder or owner.

Administration of construction at the site is usually the prerogative of the civil engineer. A schedule must be established and maintained to the end that the job will be finished on time and penalties assessed by the owner due to delay in completion avoided. Most of the work on any structure today is handled on the basis of subcontracting. One of the principal jobs of administration is to locate responsible subcontractors who will show up on the job when needed and do good work for a fair price. That is a very simple statement and it is not intended to lightly pass over one of the principal causes for headache by any civil engineer trying to administer a construction project.

Obviously, the main objective of the engineer in charge of building any structure is to complete the job within the bid price and in conformance with the specifications. This means close attention to all phases of the work and on large projects the organizing and directing of a competent staff. This particular talent is gained only through experience and the engineer who has it is always in demand.

It is very seldom that a structure of any consequence is designed or built without the services of a civil engineer somewhere along the line. His work may not be readily apparent to the general public but it is there. Perhaps his greatest contribution lies in the fact that the structure whether building or bridge is a safe one and his greatest recognition lies in the fact that the public is ready and willing to use it without questioning its safety.

The Dual Role of Engineering Mechanics

By Carl H. Walther (George Washington University)

Mechanics is the analytical tool used by the engineer whenever he deals with the action of forces on bodies. Since the engineer is concerned primarily with physical reality, it is not surprising to find that much of his work requires an understanding of principles of mechanics. I have heard one of my university colleagues, a penetrating observer with a gift for trenchant expression, say that all the equipment any engineer needs is a mastery of Newton's laws of motion. (The word mastery is, of course, italicized in his statement.) Whether one agrees with this gross oversimplification, it does serve to point up the near-universal role played by mechanics in engineering analysis and design. It may help in our attempt to understand the work of engineers, to give some consideration to engineering mechanics, its nature, and its uses.

Of course, not all engineers find themselves absorbed in the study of mechanical phenomena. Some work with the laws of electric and magnetic circuits and fields, others with those of thermodynamics and heat transfer, still others in fields of chemistry. Nevertheless, some branch of mechanics is the primary interest of so many engineers, employed in such diverse lines of endeavor, that the scientific discipline called "engineering mechanics" has come to be recognized as a separate technical division of engineering. Before proceeding further, it would be best to define the terms we use.

DEFINITIONS AND DISTINCTIONS

Webster defines mechanics as "that science, or branch of applied mathematics, which treats of the action of forces on bodies." It should be clear that, in the sense in which we use the term, it has no necessary connection with manual skill or machinery. Except for this limitation, the definition admits an extraordinarily broad class of phenomena to consideration, ranging from planetary motion to the spin of the electron. Furthermore, the approach of mechanics to a given phenomenon may be based on the laws of motion formulated by Isaac Newton, in which case it is called "classical" or "Newtonian" mechanics, or it may make use of Albert Einstein's concept of relativity and be referred to as "relativistic" mechanics.

Engineering mechanics consists of those topics of Newtonian mechanics which have technical applications. It is considered to include the study of the equilibrium and motion of rigid and deformable bodies and systems of particles, the elasticity and plasticity of solids, and the equilibrium and flow of ideal and viscous fluids. The study of the mechanical properties of materials and of applicable mathematical and experimental methods of analysis are also included, because of their intimate relation to the central subject.

It would be a mistake to conclude, from the definition just given, that engineering mechanics is merely a minor branch of the rather descriptive classical mechanics studied in undergraduate courses in physics. Although the range of problems studied is limited to those of technical interest, the detail and depth of penetration are, in comparison, enormously developed. This is natural, in view of the engineer's need for exact information. His purpose is to control natural phenomena, which implies the necessity for detailed prediction. The difference in point of view is considerable. To take an example, it is not enough for the structural designer to understand that his structure stands because all of its forces are balanced against each other in a complex of systems in stable equilibrium. He needs also to know the magnitude and kind of force in every member; furthermore, he must be able to specify precise dimensions for each member, weld, or rivet group to insure that it shall resist that force safely and economically.

ENGINEERING MECHANICS, SERVITOR AND PRINCE

Engineering mechanics exhibits a curious dichotomy in its functions and purposes. If I might borrow a theatrical figure of speech, I would say that the science plays a dual role of servitor and prince on the stage of engineering endeavor. Engineering mechanics, in one or another of its branches, is the very foundation of many engineering disciplines. Some, for example, structural, engineering, machine design, or hydraulic engineering, consist of little else than sophisticated applications of mechanics. It forms an essential structural element of others, such as aeronautical engineering or foundation engineering. The principles, applications, analogies, and techniques developed in engineering mechanics are in constant use by practitioners of these other disciplines. Needs arising in specialized fields of engineering are continual stimuli to research in the more basic field. Indeed, more often than not, the attack on a new problem in engineering mechanics is precipitated by recognition of the existence of an unsolved problem in one of the specialized fields. There is, thus, a constant flow of ideas in two directions—of needs, conveyed to the basic field, and of results satisfying those needs, transmitted to the fields of application. In this sense the role of engineering mechanics is the analogue of that of servant.

On the other hand, the investigator in engineering mechanics possesses a truly princely freedom. The science deals with fundamental principles of great generality; at the same time its expansion has related these principles to many specialized engineering disciplines and specialized areas within its own field. In consequence the opportunities for investigation are almost without limit. The rising of a bubble or the settling of a particle of sediment may claim attention. The flow of air past an airfoil and the forces exerted by the wind on a structure are related problems of daily practical interest. The rational proportioning of a member of a bridge, the behavior of the subsoil under a foundation, and the effect of stress on the knitting of a fractured bone all possess an element of common interest to the student of engineering mechanics.

In addition, engineering mechanics possesses a closely-knit core of fundamental principles common to all of its branches. This, and the analytical and rather mathematical nature of the subject permits the investigator to move from field to field and produces fruitful analogies between fields and with other sciences. The experimentalist finds room for his talents; experimental approaches to problems in all areas of engineering mechanics have been highly successful and there exists a well-developed literature devoted exclusively to experimental analysis.

It appears that we have here a scientific discipline which is at the same time prince and servitor: by turns theoretical, experimental, and resolutely practical. This duality of role must color any attempt to convey a useful understanding of engineering mechanics and its relation to other branches of engineering. It dictates the plan of organization of the remainder of this paper, in which it is proposed to direct attention to the two questions: First, how is mechanics (or engineering mechanics, if you like) used in other engineering disciplines? Second, what types of problems are of interest to investigators in the science of engineering mechanics?

USES OF ENGINEERING MECHANICS

Engineering mechanics has been pictured as a supporting science, as a sort of servitor of more specialized engineering disciplines which use its principles and techniques to further their own ends. To list these would be simply to list all those branches of our diversified and always-expanding engineering technology which deal with the equilibrium or motion of solid objects, of liquids, or of gases. It would obviously serve no useful purpose to attempt it here. Nevertheless, merely defining (as above) the criterion for inclusion in the listing emphasizes the breadth of the concerns of engineering mechanics. The way in which one of these specialized engineering disciplines makes use of principles and techniques of mechanics in routine design work will be taken up later, after first considering an analogy which illustrates still another fundamental relation between mechanics and other sciences.

AN ILLUSTRATIVE ANALOGY

The connection between mechanics and other engineering disciplines, which do not deal directly with the motions of solid bodies or of fluids, may perhaps not be so clear. A brief consideration of the performance of the loudspeaker of the currently very popular high-fidelity system for the home reproduction of recorded sound will illustrate the relation by analogy that often exists between mechanics and other apparently unrelated sciences. In the common "bass reflex" speaker system found in many "hi-fi" installations, the speaker cone is housed and mounted in an opening in the front of the box-like cabinet, and by its vibratory motion produces the sound waves which reach the listener's ear. The paper cone of the speaker is set in motion by alternating electric currents originating, 'way back in the phonograph, from the motion of the stylus in the record groove. Sound waves, which is to say pressure waves in the air, are also given off from the back of the cone; these reach the outer air through a second opening in the front of the cabinet. The mass of air in the enclosure and vent possesses the properties of mass and elasticity, or "springiness." It is desirable, for greatest listening enjoyment, that the sound emitted by the back of the speaker reinforce the sound coming from its front, without being adversely modified by the enclosure. There are other desiderata, but this brief and drastically simplified statement is enough to identify the problem situation as one of electroacoustics. The specific problem that bedevils the designer is how to determine the necessary relation among the variables of speaker characteristics, enclosure size, and the proportions of the openings transmitting sound. It is not a simple one.

Let us now consider another problem: the motion of a weight suspended at the lower end of a coil spring. We imagine that the spring is attached at its upper end to some device which moves up and down harmonically; this device might be the hand of the observer. Common experience enables us to forecast the result: the weight will be set in motion vertically. It will bob up and down in a manner dependent on its mass, on the "springiness" of the spring, and on the characteristics of the disturbing motion imposed on the system. This is obviously a problem in mechanics, a rather simple one, as it turns out.

The two apparently quite different problems just stated, one of electroacoustics and the other of mechanics, are in fact connected in an essential way: the differential equations describing the phenomena are formally similar. In plain language this means that when we make use of the abstract representation of mathematics to describe each phenomenon, the descriptions that we write down are identical in their form, differing only in non-essentials, such as the use of the symbol (say) q in the one case wherever we used x in the other, or i in place of v. The implications of this observation are far-reaching; if we can solve one problem we have in effect solved the other. All that is necessary is the substitution of the appropriate quantities represented by the symbols in the "difficult" problem for those in the "simple" problem, and the "difficult" problem is solved!

This is what we call a mechanical analogy. There are many analogies, between problems in different scientific fields and between problems in different fields of the same science. They are usually based on a mathematical similarity, as in this case, and are, of course, diligently sought because of their great usefulness in clarifying relationships or solving problems. The example illustrates the way in which mechanics is often related to other scientific fields which might not otherwise appear to have any connection with it.

AN ENGINEERING APPLICATION

We have considered some of the ways in which engineering mechanics contributes to other areas of engineering, through the development of new techniques, through research, or by analogies. No less important is the use of its basic principles and established techniques in routine engineering work. This is probably the aspect of the subject which is most familiar to the practicing engineer, but I feel that it deserves elaboration here because it is perhaps less familiar to the reader versed in pure science.

As has been said, engineering mechanics stands as the very foundation of many engineering disciplines. Skill in the application of its principles is an essential qualification of every man who practices in these fields. This is a truism, and accounts for the intensive training in mechanics that is required of engineering students. What may not be so obvious to the non-engineer is the extent to which mechanics is used in ordinary engineering projects.

Again, in the interest of concreteness, I have selected an example in the hope that it may most clearly illustrate the way in which mechanics is commonly applied. While it is not necessarily typical of engineering problems in other fields, the design of a bridge across a river is suitable for my purposes because the problem is essentially static (and hence easily observed) and because the successive stages of its solution may be readily isolated and identified. This is a problem in the field of structural engineering. Stripped of its elements of economics, political science, and esthetics it becomes an apt example of the use of principles of engineering mechanics.

Like most design problems, this involves four essential elements or stages, as follows:

(a) The determination of the general shape and form of the structure.
(b) The determination of the loading that will probably be imposed on it.
(c) The analysis, leading to evaluation of the internal resisting forces which are required to withstand the applied loading.
(d) The proportioning of members, connections, and details to insure safe and efficient performance of the structure's function.

The first of these relates so many factors that a satisfactory solution requires the exercise of the highest order of engineering skill and judgment. Although there may be little necessity for intricately detailed calculations at this stage, here occurs the blending of art and science, of appearance, economy, and function that determines the overall suitability of the final product. It is principles, rather than techniques of mechanics and other appropriate sciences which are of greatest utility in this stage.

The determination of the probable applied forces, the loading, on the structure may call for the application of only the most elementary mechanical principles, or it may involve complex problems in fluid mechanics and dynamics. The evaluation of the aerodynamic forces on a flexible suspension bridge, for example, requires consideration of the interaction of a damped elastic system with its fluid environment. Regardless of its degree of technical difficulty, however, this stage clearly involves the use of principles of engineering mechanics.

The third and fourth essential stages in the design considered here are both repetitive applications of the principles of static equilibrium. The third, which is pure analysis, consists of the consideration of first the entire structure, and then each of its members as an isolated body subjected to forces. The external and internal forces necessary to insure equilibrium are determined by this process. In the fourth stage the members, connections, and details are assigned their final dimensions. The mechanical properties of the materials to be used enter here, as well as the sometimes conflicting requirements of safety and economy. The method used is essentially one of comparison of the strength of the material with the stress imposed on it, as determined by application of principles of the elasticity or plasticity of solid bodies.

It will be noted that, although other factors sometimes assume primary importance and a staggering amount of detail makes it easy to lose sight of essentials, every stage of this design requires direct application of principles or techniques of engineering mechanics. Other fields of engineering design or analysis make similar use of the same or closely related principles and techniques, in approximately the same logical order, to solve their special problems. The example considered here is representative and demonstrates the extent to which engineering mechanics contributes to many engineering undertakings.

PROBLEMS OF ENGINEERING MECHANICS

The preceding description may serve to clarify the role of engineering mechanics in routine engineering work, but it fails to answer the equally interesting questions:

what topics are the concern of engineering mechanics, or otherwise stated, what specific problems are investigated in the field of engineering mechanics?

An indication of the general topics with which engineering mechanics is concerned may be obtained from a study of the organization of the Technical Division on Engineering Mechanics of the American Society of Civil Engineers, which is representative of groups working in that field. There are seven technical committees of the Division, in addition to the usual executive committee, namely:

Elasticity
Experimental Analysis and Analogues
Fluid Dynamics
Mathematical Methods
Mechanical Properties of Materials
Plasticity Related to Design
Structural Dynamics

While this scheme of organization or subdivision is admittedly somewhat arbitrary, (others, slightly different, are in use by technical divisions of other societies) it will serve for our purposes of classification.

Current publications give another indication of topics of interest to investigators in the field of engineering mechanics. The four most recent issues of the Journal of this Technical Division, taken as a sample, contain 19 papers.[1] All seven of the subdivisions listed in the paragraph just above are represented, with not less than two nor more than four titles assignable to each. Exact classification of some of the titles is difficult; some of the papers cut across boundaries between subdivisions. Other engineering societies, in the United States and elsewhere, regularly issue publications devoted to engineering mechanics or to one of its subdivisions. The Proceedings of the International Congresses of Applied Mechanics are voluminous, and papers on various topics of engineering mechanics also appear in the journals of nonengineering societies. In addition, the bulletins and other occasional publications of universities and Federal Government agencies contain a high proportion of titles relating to engineering mechanics. The over-all distribution of titles among the various subdivisions of the subject is roughly the same as above. One can, therefore, conclude that all subdivisions are sufficiently vital, from the standpoint of productivity at least.

The greatest number of titles in the four issues of the Journal sampled refer to elasticity and fluid dynamics, closely followed by plasticity, structural dynamics, and mechanical properties of materials. Such a superficial approach as the mere counting of titles is likely to be misleading, since it fails to take account of such factors as relative age of subdivisions (which tends to affect the number of investigators who have become interested in each) and extent of financial support of research (which, likewise, tends to affect the number of workers). To that extent the method is subject to criticism. In this case it coincides roughly with my own admittedly subjective valuation, which assesses the subdivisions of fluid dynamics, plasticity, and structural dynamics as those of greatest vitality. Actually, it is difficult to distinguish among the subdivisions on the arbitrary basis adopted, because of the intimate relation to elasticity to structural dynamics and of mathematical and experimental analysis to all three.

Adopting the different viewpoint that classifies problems as static or dynamic and linear or nonlinear, respectively, one would conclude that the areas of greatest activity are those involving dynamic and nonlinear problems. In fluid mechanics attention is focused on phenomena of flow around immersed objects and through open channels and pipe entrances. Current investigation bears on steady nonuniform flow, that is, flow in which conditions vary from point to point but are independent of time in a given region. Unsteady flow, in which conditions are not time-independent, presents formidable difficulties in all but the simplest cases and has not yet yielded many solutions. A vital field in solid mechanics is the investigation of dynamic effects, including vibration, impulsive forces, and impact, and the response of materials and structural elements to them. Considerable progress is also being made in the nonlinear problems of elastic-plastic behavior of materials and the design

[1] Journ. Eng. Mech. Div., EM 1-2-3-4, Proceedings, ASCE 82.

of structural elements to function in that nonlinear range where Hooke's law no longer applies. Elastic and plastic instability of members subject to forces tending to produce buckling is another essentially nonlinear problem receiving attention.

Prediction is a risky business, and I shall leave it to others who are presumably more competent at it. Nevertheless, two developments have yielded such significant results that no great element of risk is involved in forecasting their future extension and productivity. The first is the general attack on nonlinear problems. This is of interest because it represents a genuine advancement of a frontier of knowledge. Nonlinear problems are inherently more difficult than linear ones, since their mathematical presentation is of a higher order of complexity. At the same time, many natural phenomena are nonlinear and solutions which assume them to be linear have been less than satisfactory because they do violence to the facts. A few successful solutions, which are already in process, may be expected to point the way to others. A whole new field of problems is opening up as a result.

A second significant development is the use of a rational combination of theoretical analysis and experiment to solve problems which do not yield to either of the above methods applied singly. This approach has proven itself, notably in the field of fluid mechanics, whereby that science has proved so much more fruitful than either classical hydrodynamics or empirical hydraulics which preceded it. It is being applied increasingly in the fields of structural dynamics, elasticity, and plasticity. The procedures are already well established; the future is for expansion and for extensions of the analytical methods to other fields. The success already demonstrated leaves no room for doubt of the analytical potential of this approach.

A theory is a supposition we hope to be true; a hypothesis is a supposition which we expect to be useful.—G. J. STONEY.

The Role of the Civil Engineer in Applied Economics

By Samuel H. Gale (American Society of Civil Engineers)

Economics, by generalized definition, is the science of management of means and resources to increase productiveness and avoid waste. Civil engineering has exactly the same general purpose. Each civil-engineering project involves the consumption of resources in labor and materials to produce goods and services for use in filling existing or imminent needs. Elimination of waste from the process and increase in production effectiveness to the maximum will produce the greatest value of the undertaking. This goal can be reached only by proper application of economic principles. Accordingly, economics is the complement of civil engineering in planning, constructing, and operating civil-engineering works for the greatest benefit to our economy.

All well-planned and efficiently executed civil-engineering works demonstrate the application of fundamental economic principles. Economic considerations are involved in each phase of project accomplishment from inception to and including operation. Among the more important of these considerations in the general order of their application are: (a) Establishing the extent of need for the project; (b) comparison of alternatives; (c) fixing the optimum scope and scale of development; and (d) determining the degree of economic justification. Each step is not exclusive in the phase of its application since all are largely interrelated. The final result is reached by a process of initial approximation, adjustment, and refinement of detail as the ultimate solution is approached.

ESTABLISHMENT OF NEEDS

The nature, location, and magnitude of unsatisfied needs or demands which can be met within the physical limits of development of a proposed engineering project are listed and analyzed to establish a sound basis for the undertaking. Needs or demands must exist or be reasonably prospective in sufficient magnitude to utilize and so give value to the products and services to be provided. Without a demand for its use, a product is valueless. Normally civil-engineering works are proposed to supply a specific need or group of needs. However, it would be shortsighted and wasteful to omit consideration of all other needs which might also be met in whole or in part by the proposed works through additions, modifications, or alterations of physical composition and function to achieve the optimum value of production capabilities. Accordingly, such additional needs or demands as may be met in conjunction with the primary purpose of the undertaking are appraised and classified by relative importance. Further consideration is then directed to the satisfaction of the more important needs which can be served in order to assure the most rewarding returns from the enterprise.

COMPARISON OF ALTERNATIVES

All available means of meeting established needs should be carefully examined and compared in order to make certain that the proposed works are the most economical means of supplying the demands. Other opportunities for supplying any or all of the established needs may exist and should be compared with the proposed undertaking. For example, secondary sewage treatment to solve a pollution problem might be found more expensive than the construction of a small reservoir for low-flow regulation and adequate dilution. Possibilities for meeting needs by means other than the construction of physical works may exist and if so should be considered. Legal zoning against occupation of a frequently flooded area might avoid the necessity of constructing levees or other physical flood-protection works. By such comparisons with feasible alternatives, the proposed project is tested to prove whether it will have greater efficiency in meeting established needs than any available alternative.

Alternatives are compared by measuring the influences of each on the availability of goods and services. Such influences relate to the goods and services consumed in placing and maintaining each item of improvement in effect (costs) and the goods and services

each will produce (benefits). Cost estimation is in the primary field of civil engineering and needs no elaboration here except for caution that all costs both direct and associated must be taken into account. Associated costs include such losses as may occur from elimination of existing economic values. For example, loss of agricultural production on land within the flowage of a reservoir may result not only in the loss of value of the production as reflected in the direct land cost but also in additional loss from depreciation of the value of existing enterprises established for processing the agricultural products. Benefits may include both tangible and intangible values. Tangible benefits are those products of goods and services for which a market value can be established. Intangible benefits, while nonethe-less real, are not susceptible of pricing. An example of the latter is the improvement of public health and welfare. Both benefits and costs can be established most accurately by comparison of the availability of goods and services under conditions with and without the undertaking.

The process of comparing alternatives begins with the elimination of the obviously infeasible from the complete array. In less obvious cases, physical and engineering factors reflected in the comparative costs often provide the basis for elimination. Rough estimates of cost and approximations of the principal benefits will further suffice for conclusive determinations of inferior alternatives. As greater refinements become necessary to define relative value, more detailed estimates of cost based on field data of corresponding accuracy and more complete estimates of benefits taking into account both tangible and intangible effects, are required. Concurrent with the necessity for increasing detail of analysis, consideration is given to the optimum scale and scope of the alternatives to make sure that the definitive comparison is made at the most effective level of their potentialities. The fundamental basis for comparison and choice from two alternatives is their respective benefit-cost ratios. Since the benefit-cost ratios reflect only the finite monetary values their comparison must be supplemented by comparison of the respective intangible values. Benefit-cost ratios are directly comparable but intangible effects are qualitative and not necessarily expressible in common terms. The indications of the finite comparison must be modified by judgment of the respective intangible values in arriving at the final choice.

OPTIMUM SCOPE AND SCALE

The most desirable extent of an undertaking, from the standpoint of the users of the goods and services it could provide, is that which will satisfy completely all existing and prospective needs. However, from the standpoint of efficiency in the use of goods and services, this maximum scale of development is seldom if ever practicable for economic reasons. A determination of the optimum scale and scope of the project must be made by a series of adjustments of increasing refinement. A reasonable starting point is that extent of development which will provide for the satisfaction of the more important needs and also meet needs of lesser priority within the limit of physical capability. This extent is then adjusted downward by practical increments to the point where the excess of benefits over costs is the maximum.

Incremental adjustments apply to variations in the scope of the undertaking to omit separable provisions for less important needs; and, variations in the scale of the separable elements of the undertaking which are required to meet the more important needs. The smallest increments to be considered in successive adjustments and analyses are those for which there is a practical choice as to their inclusion or omission. Practical increments vary with the considerations involved. In a reservoir project, for example, small variations in height of dam can be analyzed by comparing the incremental costs with the value of the corresponding increment of storage. Sometimes entire segments of an improvement which add to the degree of service, such as entire generating unit in a power plant, may constitute the smallest increment to be considered as to the advisability of its inclusion or omission. In an undertaking designed to meet several objectives, the smallest increment for practical analysis may consist of all separable features for one of the purposes.

The scope of an undertaking refers to the

number of purposes it can serve, that is, the number or types of established needs which can be met in whole or in part. If only a single purpose is involved the scope is automatically fixed although the extent to which an undertaking can serve that purpose depends on its scale. The scale of an undertaking refers to its established capability to meet the needs for which it is intended. Both scope and scale may be fixed at the point of optimum efficiency by incremental analysis. For the more simple case of a single purpose undertaking the optimum scale of improvement is found at the point where the ratio of incremental benefits to incremental costs is unity and no additional increment is capable of providing additional benefits equal to its costs. When an undertaking is proposed to serve several purposes without separable provisions for each purpose a series of incremental adjustments between purposes must be analyzed for each increment of project scale. By this means the most effective balance between purposes is assured at each incremental stage of the analysis made to fix optimum scale.

Application of sound procedures of economic analysis to the design and test of a proposed undertaking should also be made to insure that each component of the project represents a more effective means of accomplishing its intended purpose at less cost than any practicable alternative which it would preclude from development or use. Moreover, the scope and scale of the planned works will have been established at the point of maximum return with respect to the costs involved. Accordingly, the entire plan comprised of properly sized components will provide for the most effective and economical use of goods and services required in its construction in comparison with the goods and services it can produce to meet established needs. But the degree of justification for the undertaking must still be determined.

ECONOMIC JUSTIFICATION

At this point the designs and estimates of cost will have been finalized according to standard practices in detail commensurate with the standard of precision appropriate to the purpose. All benefits creditable to the undertaking in its established scale and scope will have been identified. The degree of economic justification is then established by comparison of the benefits with the economic cost of providing them, taking into consideration the ratio of monetary benefits to total costs on a mathematical basis, and, by applying sound judgment, weighting that ratio by the qualitative influence of the pertinent intangible benefits. Obviously, if the benefits of an undertaking, so adjusted to optimum efficiency in the consumption and production of goods and services, exceed the total costs by a reasonable margin, the justification for its construction is established and its success is fully assured.

THE CIVIL ENGINEER'S ROLE

It is evident from the foregoing that the role of the civil engineer in the application of economics is dominant in his field. Each step of project formulation and refinement couples the application of economic principles with the application of engineering principles. In examining the economic needs to be served, knowledge of the engineering ability to serve them is required. The comparison of alternatives exercises all the engineering skill and all the judgment of economic factors possessed by the analyst. The optimum scope and scale of the proposed improvement can be determined only by a combination of knowledge of cost factors and of production factors as affected by incremental changes. And finally, the appraisal of over-all justification for an undertaking again requires the coupling of engineering knowledge of cost and performance with understanding and judgment of economic returns.

In recent years increasingly complex and extensive projects and the higher costs of labor, equipment and materials have intensified the need for careful and thorough planning in order to make certain that the proposed improvements would constitute the best use of available resources and provide returns commensurate with the costs. Accordingly, the civil engineer is called upon more and more for his contribution of knowledge and judgment to the proper design of projects and accurate estimates of their value for the development and utilization of those resources. His engineering skill, knowledge, and appreciation of economic principles, and his vision guided by conservative practicability, enable the civil engineer to be particularly well fitted for his increasingly important role in planning and accomplishing projects to meet the needs of our expanding economy.

The Role of the Civil Engineer in Power

By Harrison G. Roby (Consulting Engineer)

In looking over the various fields of endeavor in which the civil engineer is engaged, it will be recognized that power gives him an opportunity to use an unusually wide range of technical engineering knowledge. This is particularly true in regard to hydropower. Thermal power calls more for the contributions that can be made by the mechanical and electrical engineers, although there is need also for the civil engineer to take part in the several phases of such a project. His duties include the survey work involved in the layout of the steam plant, the design of intakes and passages for condensing water and design of the power-plant structure. In the case of coal-burning stations, he plans and supervises construction of railroad access lines or barge unloading facilities, coal storage areas and recovery arrangements. Structural design of transformer and switching stations and also the survey and design of transmission towers and lines, are a part of his field.

In development of water power, the position of the civil engineer is reversed, and he assumes the major part of the engineering duties with necessary and useful contributions from the mechanical and electrical engineers. The engineering features that must be taken into consideration in planning a hydro project are never quite the same as at other projects, and the civil engineer must have at his command knowledge of a wide and diversified list of engineering subjects. This diversity of natural conditions results in the requirement that each project shall be a made-to-order tailored job, and the possibility of reproducing a prior development at a second site is entirely absent.

The first step in the study of a hydroproject is a reconnaissance of the river basin in the area proposed for the dam site. The purpose of a reconnaissance is not to determine the economic feasibility of a project, but to ascertain whether it is probable that a more thorough study will show that it is economically sound. Therefore, the preliminary field work and office study should be limited to the amount necessary to arrive at the answer as to the probable results of a more complete investigation.

The reconnaissance should include cross sections of the valley at possible damsites, and a geological investigation of foundation conditions. The quality of the foundations and the practical height of proposed dam will determine the type of dam that would be built, the choice resting between concrete, earth fill or rock fill. A search should then be made to locate a source of supply of the material of which it is proposed to build the dam.

A flow line should be run out and an approximate area-capacity curve obtained which will indicate the amount of storage available, the land that must be acquired for reservoir purposes, and necessary relocations of railroads, highways, dwellings and villages.

Since the dependable power at a hydro project is a function of head times regulated flow, the preliminary investigation requires a knowledge of expected stream-flow at the damsite. For many years the U. S. Geological Survey has kept a daily record of flow of practically all streams in the United States that have power potentialities. If no stream-gaging station is located at the proposed damsite, the flows at that site can be roughly obtained by multiplying the records by a constant based on relative drainage areas at the nearest gaging station and at the damsite.

If this preliminary investigation is favorable, the next step is the "survey" stage, which is carried to the degree of thoroughness necessary to determine the "benefit-cost ratio" or the economic feasibility of the project. Borings are made at the damsite, and the costs of the different types of dams that can be constructed at the site are computed and compared. A mass curve is developed which shows the period of critical low flows, and with information as to reservoir capacity secured by aerial photography, a study is made of the available storage to

secure the highest average flow that can be obtained during this critical period. As the reservoir is drawn down and the operating head is reduced, the flow will be correspondingly increased to give a constant power output. This value multiplied by the reciprocal of the load factor desired from this station by the system determines the plant installation.

A layout of dam, power plant, and spillway is made, and a cost estimate prepared. This estimate includes also the purchase and clearing of reservoir lands, the cost of relocations and the control of river-flow during construction. To the fixed charges on the original cost is added the annual cost of operation and maintenance to find the total annual cost of the hydro power.

The economic feasibility is then determined by comparing this cost with the cost of equivalent steam power in the region, which is used as a yard-stick, since it is always possible to supply an area with power from a thermal plant. In certain areas the yardstick will become the cost of atomic power, but within the United States with relative abundance of coal, oil, and natural gas, this time lies in the distant future.

Probably the most important function of the civil engineer engaged in water power practice is the design of hydraulic structures. Concrete dams must meet this criterion: the weight of the concrete and the width of the base shall be sufficient to resist the water pressure which tends to cause overturning or sliding. Earth fill and rock fill dams must be provided with an impervious core of compacted clay material, with drainage of the downstream sections and with riprap on the upstream face to prevent erosion by wave action.

To prevent erosion of the foundation material at the toe of the spillway section, the engineer must provide a stilling-basin to absorb the kinetic energy of the water discharged through the gates, or a flip-bucket to throw the water a sufficient distance downstream so that erosion will not endanger the structure.

Flood gates must be designed with sufficient discharge capacity to pass the largest possible flood. They are usually one of two types: either vertical lift gates with rollers, or sector gates with a cylindrical face and frames carrying the thrust of the water back to pins anchored in concrete piers.

The power house structure, with intake, racks, gates and water passages becomes an integral part of the dam in the case of relatively low-head developments. At higher head projects, the intake is built into the dam structure and penstocks lead the water to the power house which is entirely independent and has no function in regard to the stability of the dam.

In the construction of the dam it is necessary that the engineer work out a method for control of the river flow at the damsite. There are two methods of stream diversion and cofferdam construction. At a site on a river which is relatively wide, a portion of the river bed is unwatered by building out from one bank cribs or cells which divert the water away from this area to the area on the opposite side of the stream. Sections of the dam built in the unwatered area are left low, and in the second stage of construction, the first cofferdam is removed and a cofferdam is built from the opposite shore, diverting the water through these low sections. After the dam is built to full height in the second cofferdam area, the low sections in the first area are successively blocked off and built up.

In canyons this method of water control is not feasible. The procedure used in narrow river channels is to drive a tunnel around the site, large enough to take the maximum flow anticipated during the construction of the dam. After this is accomplished, coffer dams are placed entirely across the river, upstream and downstream of the dam axis, and the area then unwatered. After the dam is completed, the tunnel is blocked off with a concrete plug.

The civil engineer engaged in hydro development must be acquainted with the needs of the power market that the project is being built to serve. There are two types of water power projects each of which has quite a different function in supplying power to the area: run-of-river plants and storage developments. Run-of-river projects are those of relatively low head and big flow, which have no storage capacity and must use the flow approximately at the rate at which

it comes to the plant. Their main value is the contribution of energy to the system and the saving of fuel at steam stations. During floods, the rise of tailwater level cuts down the plant capacity and in some cases reduces the output to zero.

Storage projects, as the name implies, have the ability to store streamflow in the reservoir above the dam and to develop power as needed by the system. The particular value of these developments is capacity; the capability of supplying kilowatts during the peak of the system load. These projects usually have relatively high dams and are often economically justified at sites with small or medium drainage areas. They are low load-factor plants, operating a relatively few hours per day, per week, or per year.

In selecting the proper hydraulic equipment for a hydro plant, the civil engineer must be familiar with the different types of water turbines. For relatively low heads, up to about 100 feet, the propeller type is used. One hundred feet is the maximum head for which this type has been used in the United States although European practice permits use at somewhat higher heads. The speed of a propeller runner, in R. P. M., is greater than that of the other types, thus cutting down the number of poles and reducing the cost of the direct-connected generator. It is also capable of passing more water. There are two kinds of propeller turbines: fixed blade and adjustable blade or Kaplin design. For plants with relatively few units the adjustable blade model is particularly adapted, since by changing the pitch of the blades for changes in load it can maintain a very high efficiency even for very light loads. In a plant with a large number of units, the fixed blade type is used as it is lower in cost. As the load changes the number of units in operation can be increased or decreased, keeping each unit at the load point at which it is most efficient. Most run-of-river installations use propeller turbines.

At projects with heads ranging from 100 to about 800 feet, the Francis type is used. By far the largest number of water wheels in use in the United States is of this type. Its efficiency at best gate is high, 93% to 94%. At part gate it is more efficient than the fixed propeller type, but not as efficient as the adjustable blade propeller unit. It can be cast in one piece up to about sixteen feet in diameter. The largest single piece unit of this type is installed at Grand Coulee and is rated at 150,000 horse power. A few Francis units of larger diameter have been built in segments which were assembled and held in place by bolts or by shrinking on an outer band.

The type used for very high heads is the impulse wheel. Water discharged at a high velocity from a nozzle impinges on buckets attached to the periphery of a disc which is mounted on a horizontal shaft to which the generator is also attached. This type is not as efficient as the other ones but it is rugged and cheap.

During the last half century, the civil engineer has encountered ever-increasingly larger and more difficult problems in the development of power. With the tremendous increase in demand for electric energy the size of units has been magnified, the number of units per station has greatly increased, with the result that thermal stations of over 1,000,000 kilowatts capacity and hydro plants ranging from 1,500,000 to 2,000,000 kilowatts in capacity are becoming common. As the better sites are being preempted, the civil engineer is finding it necessary to develop sites that formerly would not have been considered suitable, and he has shown commendable ingenuity in meeting these conditions.

The Role of the Civil Engineer in Surveying and Mapping

George D. Whitmore and Morris M. Thompson (U. S. Geological Survey)

Today's science of surveying and mapping has assumed a scope and significance that George Washington could scarcely have imagined when he traversed the Virginia countryside with compass and Jacob's staff. In Washington's day, there were two kinds of engineers—the military engineer, who was concerned mainly with the construction of fortifications and engines of war, and the civil engineer, who was concerned principally with developing the best routes for roads, bridges, canals, aqueducts, and other transportation facilities. The development of these route locations resulted primarily from surveying and mapping activities; thus, the term "civil engineer," prior to the industrial revolution, may be considered as practically synonymous with "surveyor and mapper."

As the modern industrial era developed, the separate field of mechanical engineering came into being, to be followed later by many other specialized fields, like chemical, electrical, and aeronautical engineering, which make up the vast complex of present-day engineering activities. In the meantime, there has developed within the older field of civil engineering itself, a steadily expanding array of specialized activities, so that the American Society of Civil Engineers today has 13 separate divisions, whose diversity of interest may be exemplified by citing the names of three: structural, hydraulic, and surveying and mapping.

The professional challenge in the field of surveying and mapping has grown greatly with the ever-increasing demand for more and better surveys and maps, produced in less and less time. Modern techniques of surveying and mapping have advanced so rapidly, especially in the last 10 to 20 years, that there is scarcely a link in the chain of mapmaking procedures that has not undergone some recent change. Unless he is satisfied to be left hopelessly behind, the engineer in surveying and mapping today must be familiar not only with classical surveying methods, but with such modern scientific disciplines as photogrammetry, electronic measuring techniques, and data-processing systems. Articles on surveying and mapping subjects, appearing in technical journals all over the world, bear an increasing weight of advanced mathematical content, involving concepts far beyond the ken of the surveyor of 20 years ago.

SOME MODERN SURVEYING AND MAPPING TECHNIQUES

The factor that has had greatest effect in modifying traditional surveying and mapping procedures is the application of photogrammetry, the science of making reliable measurements by the use of photography. With the aid of precise aerial photographs and ingenious stereoscopic map-plotting instruments, many surveying and mapmaking operations have been transferred from the site of the survey to air-conditioned offices in far-off cities. This is not to say that fieldwork and classical surveying procedures have been eliminated. On the contrary, there is more field surveying than ever because there is so much more mapping being done. For a long time to come, fieldwork will be necessary for geodetic control surveys, for mapping areas not suitable for photogrammetric mapping, and for the surveys and investigations that are required to complete the photogrammetrically compiled original map drawings.

Much of the laborious aspect of old-time fieldwork has, however, been eliminated. With the aid of helicopters (Fig. 1), it is now possible to occupy survey stations that could be occupied only after days of climbing, or perhaps not at all, in the old days. No longer is it necessary to sketch contours in the field and to obtain a multitude of rod readings in order to control this sketching. The 3-dimensional optical model of the terrain which is viewed by the operator of a stereoscopic plotting instrument presents, in effect, an infinite number of rod readings and the contours can be drawn accurately and speedily. (See Fig. 2.)

FIG. 1.—The "toadstools" would have been difficult to use for control stations without the helicopter. (Courtesy U. S. Geological Survey.)

The science of photogrammetry has at its disposal a great variety of elaborate plotting instruments such as the stereoplanigraph (Fig. 3). The engineer directing mapping operations must not only be well-versed in the optical and mechanical principles of these instruments, but he must also be able to plan in detail the entire sequence of operations for each particular mapping project.

In addition to the quantitative aspect of photogrammetry, as represented by the techniques for measuring heights and distances, there is the qualitative aspect known as "photointerpretation." What is represented by an image of a certain size, shape and density on a photograph? What is the significance of certain patterns of light and shade? These questions lie within the domain of the photointerpreter. The science of photointerpretation must, of course, be mastered by the mapmaker if he is to transfer information properly from the photograph to the map.

Electronic science has also had an important effect on surveying and mapping techniques, especially as applied to the measurement of distances in the field. A number of electronic systems—Shoran, Loran, Lorac, Hiran, P. P. I., Decca, and Raydist—have been applied with varying degrees of success to this problem. One of the most promising developments is the geodimeter, a system in which a modulated light beam is directed from one survey station to a reflector set up at a second station, with the distance between the two stations being determined as a function of the phase difference between the emitted beam and the reflected beam, and the precise value of the velocity of light. Distances up to 20 miles have been measured

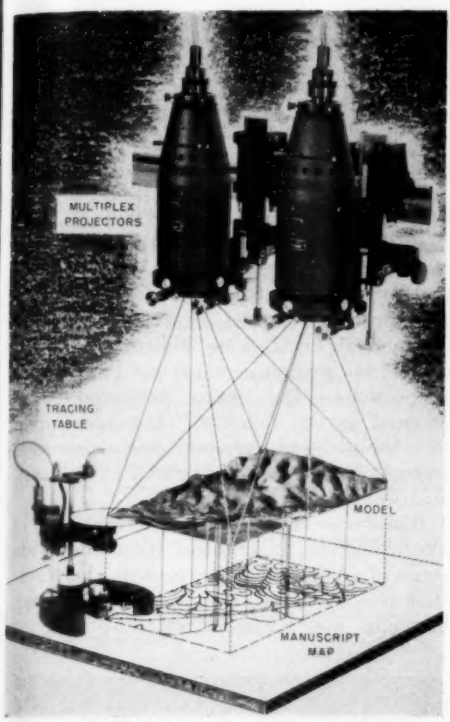

FIG. 2.—Principle of the multiplex. The optical model formed by a pair of projected photographs is converted to a topographic map by means of the tracing table, a device for measuring and drawing details of the terrain. The photographs used in the multiplex projectors are printed on glass slides, called diapositives. A red filter is used in one projector, a blue-green one in the other; the observer wears corresponding spectacles to obtain the 3-D effect. (Courtesy U. S. Geological Survey.)

in this way with an accuracy good enough for geodetic triangulation lines.

Another electronic development, the radar altimeter, measures variations in the height of terrain by emitting a radar beam from an airplane traveling at a constant pressure altitude. The beam bounces off the ground back to the airborne radar equipment. The terrain clearance (height of the airplane above the ground) is a function of the elapsed time; the ground elevation is determined from the altitude of the airplane and the terrain clearance. (See Fig. 4.)

These electronic applications are, as one might suspect, rather complicated in execution and have been presented here in extremely simplified form.

MAJOR SURVEYING AND MAPPING PROJECTS

Some idea of the magnitude and significance of the task confronting engineers responsible for major surveying and mapping projects can be gleaned by examining only a few of the larger undertakings.

Topographic Map and Geodetic Survey of the United States.—With the continuing industrial and economic development of our country, the exigencies of national defense, and the increasing appreciation and use of maps by the public, the production of the atlas of topographic quadrangle maps must be vigorously pursued until the entire area of the United States and its Territories has been covered. This tremendous program of complete and adequate topographic mapping of the entire country (which could be completed within 15 to 20 years if current production rates can be maintained) is being carried out under the direction of the U. S. Geological Survey. The prerequisite geodetic control surveys are executed by the U. S. Coast and Geodetic Survey.

Inter-American Geodetic Survey.—An outstanding example of international cooperation among nations is the work of the Inter-American Geodetic Survey, which functions as an organization of the U. S. Army, Caribbean. The IAGS maintains headquarters in the Canal Zone, with project offices in each of the 18 Pan-American nations represented in the enterprise. Although staffed by officers of the Corp of Engineers, most of the IAGS employees are civilians including many civil engineers. The principal aims of the organization are to establish a common geodetic datum for Central and South America, to connect this datum with the North American geodetic datum, and to assist the participating nations in mapping their own countries. The IAGS, established in 1946, has made substantial progress toward the accomplishment of these objectives.

Worldwide geodetic datum.—Modern activities of both peace and war require more exact data regarding the shape and size of the geoid, which in turn requires the deter-

mination of the optimum worldwide geodetic datum. Thus we find many of the leading nations of the world, in addition to those of the Western Hemisphere, cooperating in a gigantic effort to connect the geodetic surveys of all countries within each continent, and also to connect all continents with each other, often by means of long geodetic distances measured electronically. These activities are under the leadership of engineers in the geodetic unit of the U. S. Army Map Service and similar organizations in other countries.

Antarctica mapping.—Although some mapping has been done in the past on the fringes of Antarctica, there still remains the imposing task of mapping the entire continent. Because of the interests of several countries in the Antarctic, mapping activities in that area have far-flung international ramifications, as well as formidable technical difficulties. A renewed impetus has lately been given to this challenging enterprise by the program of the International Geophysical Year. At the time of this writing, expeditions representing several nations are in the Antarctic, obtaining photographs and other data needed for further mapping of that frozen continent.

Wartime mapping.—Under emergency conditions, the entire capacity of the mapping profession, public and private, can quickly be transferred to war needs. During World War II, the surveying and mapping facilities of such diverse organizations as The Geological Survey, the Army Map Service, the Tennessee Valley Authority, the Coast and Geodetic Survey, and a number of commercial firms, were enlisted in a coordinated mapping effort of mammoth proportions. The maps produced were counted in the millions. Thousands upon thousands of aerial photographs, many over enemy territory, were procured by military aviation for mapping purposes.

World aeronautical charts.—World War II also brought a requirement for a worldwide series of aeronautical charts, with the result that the U. S. Air Force now has a large mapping and charting establishment at

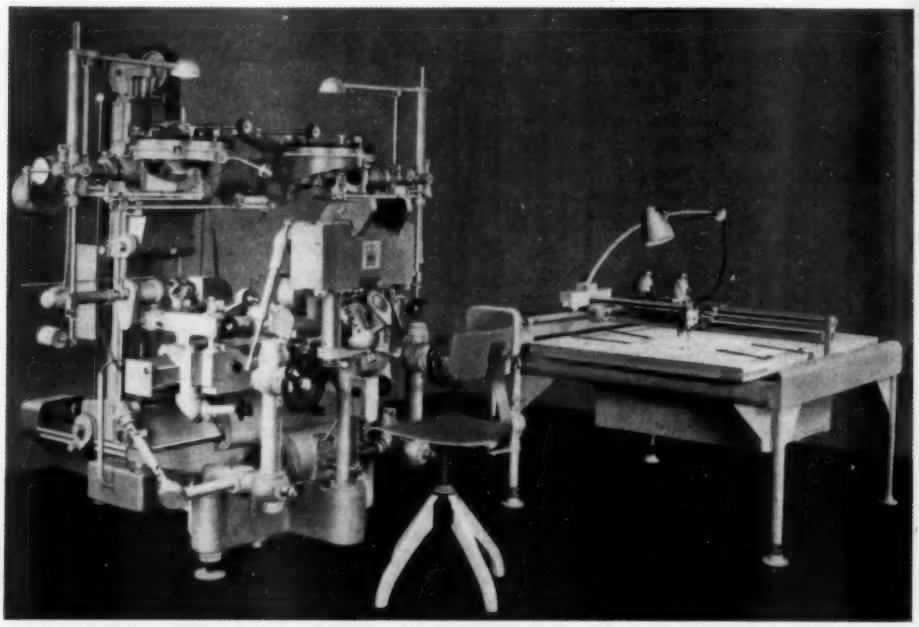

FIG. 3.—Stereoplanigraph. This complex, but highly efficient, plotting instrument is used in making accurate topographic maps from aerial photographs. (Courtesy Zeiss Aerotopograph.)

St. Louis, known as the Aeronautical Chart and Information Center (ACIC).

Hydrographic charts.—Large organizations are also required to produce and maintain the hydrographic charts required for the Navy and Merchant Marine. For these activities, the U. S. Coast and Geodetic Survey maintains an extensive hydrographic survey organization for producing and revising charts of U. S. waters, while the Hydrographic Office of the Navy has a similar organization for corresponding work in foreign waters.

Private-practice organizations.—The nature of modern surveying and mapping procedures, requiring large investments in costly instruments and other specialized equipment, has led to the formation of a number of private-practice firms, employing large numbers of engineers and technicians. Their principal services are the supplying of aerial photography and related products, together with engineering surveys of routes and project sites for industry and local public works agencies.

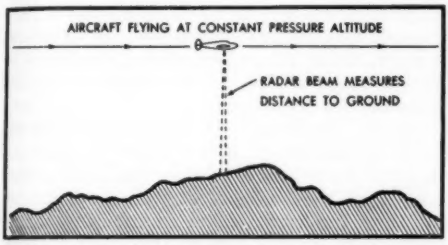

FIG. 4.—Radar altimetry. The terrain clearance under the aircraft is recorded on a moving tape. Since the constant pressure altitude deviates from constant height above sea level, the profile record must be adjusted by reference to points of known elevation along the flight track. (Courtesy Photographic Survey Corp., Ltd.)

ROLE OF CIVIL ENGINEERS

While skilled technicians can carry out many of the day-to-day jobs in the chain of operations of surveying and mapping, engineers, and preferably civil engineers, are needed to play the key roles of leadership, planning, direction, and research. Their job in surveying and mapping is to see the big picture, to fit the parts together, to keep up with what is going on in other fields of science and engineering and to know when to apply it, to take the lead in developing new equipment and techniques, to know what is needed and how to get it done, and to impart needed know-how to technical specialists.

Civil engineers can well be proud of their high level of accomplishment in surveying and mapping in the past, and they have every reason to expect that they will continue to be the leaders in the future.

STRUCTURE OF GALAXIES

The detection of radio signals with a wavelength of 21 cm (about 7 inches) has opened a new era in the study of the structure of the Milky Way system, with its hundred billion stars, and of thousands of similar galaxies in space. The signals are emitted by atoms of hydrogen and show that tenuous hydrogen clouds fill much of the space between the stars. This research has already clarified the spiral structure of our own galaxy, as Dr. Bart J. Bok, of the Harvard College Observatory, describes in a report recently published by the Smithsonian Institution. Work on external galaxies has barely started.

The 21-cm waves may be regarded as a kind of invisible light that obeys essentially the same rules as visible, ultraviolet, and infrared light, and passes easily through obscuring material. The wavelength is slightly lengthened when the radiation comes from an object moving away from the observer, and slightly shortened when it comes from an object moving toward the observer; these changes are measured and used to determine the speeds of the atoms. The direction from which the waves come reveals the structure of our galaxy, and the speeds of the atoms reveal its rotation.

Looking outward into space, one observes a vast number of great star aggregations similar to the Milky Way galaxy. The stars, in general, are arranged in the form of a coiled spiral like a watch spring. Our own galaxy has long been assumed to have the same form, but this has been difficult to observe with ordinary light. The spiral structure was verified some years ago by Dutch astronomers at the University of Leiden, who used the radio telescope to observe the 21-cm line. From Holland it is possible to survey the 21-cm emissions only from the Northern Hemisphere. Dr. Bok reports that a preliminary survey of the Southern Hemisphere has now been completed and shows about the same picture. When viewed from within, the structure of the galaxy is much more complicated than it would seem if observed from outside. The first observations made by the Dutch astronomers showed that the Milky Way galaxy has three spiral arms, in one of which the solar system is imbedded.

The comparisons to a watch spring are now seen to be "only very rough first approximations." The principal spiral features are branched and shredded. It is evident, furthermore, that not all the spiral features lie in the same plane. The complexity of galactic structure is being made more apparent by the preliminary results of Southern Hemisphere studies, made chiefly by radio astronomers in Australia.

The rotation of the galaxy, and the different rotations of various star groups within it, are well-known problems that are made even more complicated by the 21-cm observations. It has generally been assumed in the past that the stars of our vast system are moving in approximately circular orbits. The new observations cast doubt on this simple assumption.

Research on the external galaxies by means of the 21-cm line is still in its infancy. Australian observers have detected this radiation from the large and small Clouds of Magellan in the Southern Hemisphere. These are not parts of the Milky Way system, but galaxies, our nearest neighbors in space. Astronomers are already learning much about the dynamics of the Magellanic Clouds. Their rotation is well established, and good estimates of their masses can be made from the rotational velocities. Efforts now are directed toward detecting 21-cm radiation from the great galaxy in Andromeda, one of the nearest of the external galaxies, and comparable in size to the Milky Way system. The 21-cm signals from some more distant galaxies indicate considerable speeds of recession—as great as 7,000 kilometers a second. These recessions confirm the photographic observations of the speeds of distant galaxies that constitute the evidence for the "expanding universe."

SOLAR HEATING SYSTEMS

The giant planets of the solar system—Jupiter, Saturn, Uranus, and Neptune—have their own internal heating systems. Though they are far from the sun, the amount of solar heat they receive is enough to maintain a temperature of 225° below zero on Jupiter, and somewhat lower temperatures on the others. There is growing evidence that the sun is not the only source of heat these planets have, according to Dr. Gerard P. Kuiper, of Yerkes Observatory, in a Smithsonian Institution report on "New Horizons in Astronomy" recently issued. The vast "weather" phenomena observed on these planets cannot be caused by solar heat alone, but may be explained by some form of internal heat, perhaps resulting from the concentration of mass toward the center

of the still contracting planets, Dr. Kuiper points out in outlining still unsolved problems in solar system astronomy.

In the atmosphere of Saturn, for example, clouds as large as the entire earth can be detected about once a decade. They are apparently due to major eruptions from the planet's interior, Dr. Kuiper says. Because different zones of the very thick atmosphere rotate at different speeds, the clouds soon stretch out into belts parallel to the Equator. Similar cloud formations are observed, somewhat oftener, on Jupiter. They vary in color—brick red, chocolate brown, blue, amber, white.

Adequate explanations of these cloud phenomena. Dr. Kuiper states, and the clues they give to the history of the earth might go far toward solving other pressing problems of the sun's 9-planet family. It now seems apparent, he says, that at least as far as Jupiter and Saturn are concerned, the planets "do not have a sun-induced meteorology, as do terrestrial planets, but one governed largely by released internal heat," and meteorologists have already pointed out that internal heating is more efficient than the sun's heat in "stirring" a planet's atmosphere. "Do these occasional bursts (as evidenced by the clouds) come from the deep interior?" he asks. "Then how do they get through the mantle of solid hydrogen (hydrogen gas compressed into a solid by the tremendous weight of the overlying atmosphere) which usually is assumed to surround the denser core?"

There is still no adequate explanation, he says, for the gigantic Red Spot that has appeared and disappeared at intervals in the high atmosphere of Jupiter, and was seen as long ago as 1859. There is a possibility that the Red Spot may be a cloud cap over a floating island in the Jovian atmosphere. Of great interest is the recent detection of radio bursts coming at regular intervals from Jupiter, which appear to emanate from a whitish cloud. "The atmospheric clouds on Jupiter and Saturn," Dr. Kuiper says, "are almost certainly atmospheric condensation products, as is true for most of the clouds and haze on Mars. Occasionally Mars has yellow dust clouds also, while the nature of the cloud cover on Venus is still in doubt. Saturn has a general haze cover which forms the bottom of the visible atmosphere. It usually is divided into a number of distinct belts parallel to the Equator, of slightly different reflectivity and, sometimes, color."

The moons of the planets present quite distinct problems. One of the largest is Titan, brightest of the satellites of Saturn. It is orange in color and has an atmosphere of methane or marsh gas. Another of Saturn's moons, Triton, is yellow. It probably has an atmosphere, but of unknown composition. Some of the other satellites, including the bodies making up Saturn's rings, probably are cosmic masses of ice.

The rings of Saturn are unique and we still do not know, Dr. Kuiper says, why similar rings do exist around Uranus and Neptune, which presumably originated under similar circumstances. It can be understood, he says, why Jupiter has no such rings. The high density of Io, one of Jupiter's four satellites discovered by Galileo, indicates that the surroundings of the giant planet were too hot for the development of snow rings when the satellite was formed.

RESEARCH ON VIRUSES

Filterable viruses, the extremely minute particles which are the agents of some of the most dreaded human, animal, and plant diseases, now completely bridge the dimensional gap between the living and nonliving worlds. They are subject to extremely drastic mutations, or genetic changes, in nature, and these are accompanied by major changes in the diseases they cause. Thus all are dangerous. One which apparently causes no disease at all suddenly may change into a strain that is virulent or lethal. These findings are reported by Dr. Wendell M. Stanley, director of the virus laboratory of the University of California, the chemist who first obtained a virus in crystal form, in a paper published in a recent annual report of the Smithsonian Institution.

With the electron microscope, which makes these particles visible for the first time, Dr. Stanley says, the boundary between the animate and the nonanimate essentially disappears. The instrument makes visible objects with diameters of about 300 millimicrons or greater. It has rendered visible particles of viruses down to diameters of only 10 millimicrons, smaller than some of the largest organic molecules of the chemist. Between 10 and 300 millimicrons, Dr. Stanley points out, "is the range of the unknown void between the organisms of the biologist and the molecules of the chemist." This is the range of sizes that has now been filled in by the viruses.

Perhaps the most significant of recent discoveries concerning viruses, he points out, is the mutational ability and the accompanying change in disease manifestation; so that "if a host con-

tains a virus, even though a very mild or latent virus, the possibility of formation of a very virulent or even lethal virus strain always exists." Although such mutations are well demonstrated in nature, it has been impossible to produce them by directed chemical changes in their structure. For example, the amino acids constituting the virus proteins can be changed radically. Dr. Stanley's own studies have concerned chiefly the first-discovered and best-known of the "organisms"—that which causes the tobacco mosaic disease. Great numbers of amino acids, the building blocks of proteins, can be removed or added without any demonstrable effect on the infectivity. Eventual discovery of what actually takes place in the mutations, he points out, will be of very great significance.

Solution of the virus problems "undoubtedly carries the key to the nature of life itself, and possibly the key to the cancer problem." Dr. Stanley continues:

> Despite their small size the viruses represent a potential source of information which may be far more important for mankind than the atom bomb or nuclear energy. If we can discover the secrets carried within the virus structures we will have gone a long way toward making the world a better place in which to live.
>
> It may appear amazing that nature selected the border-line between the living and the nonliving worlds to house secrets of such great importance, yet sober reflection will reveal the wisdom, if not the necessity, for this course of action.
>
> Real properties of matter are but reflections of the degree of organization within, or the structure of, matter. The viruses, bridging the gap between organisms and molecules, have just that degree of chemical structure which is necessary to provide for expression of certain necessary properties, part of which lie in the world generally regarded as nonliving.
>
> Certainly some viruses are single molecules and the nature of the chemical structure characteristic of such virus molecules is a challenging problem for the chemist. Some viruses seem to consist of many molecules interacting in some special manner, and elucidation of this interaction also represents a challenging problem.
>
> As yet there appears to be no clear line of division, and it is still possible to agree with Aristotle's suggestion of more than 2,000 years ago that nature has made such a gradual transition from the living to the nonliving world that the boundary between the two is doubtful and perhaps nonexistent.

CRUSTACEAN METAMORPHOSIS

The worms, the insects, the spiders, and the crustaceans had a remote common ancestor somewhere on life's far frontiers more than a half billion years ago. Of this ancestor of earth's most abundant animals, presumably a more wormlike than buglike creature, no trace remains. This is deduced by Dr. R. E. Snodgrass, Smithsonian Institution collaborator, in a paper on crustacean metamorphosis recently published. By worms he refers to the so-called "annelids," segmented creatures such as earthworms and a host of other less-known forms.

> There is . . . ample evidence from a study of modern forms [he says] to indicate that the early progenitors of the arthropods were closely related to the progenitors of the annelid worms, and that these two groups of annulate animals had a common ancestor. The fundamental characters preserved in the annelid-arthropod organization are: an elongate segmented body, an alimentary canal extending through the length of the body [and various other highly technical features]. We may therefore visualize the primitive annulated animal as a very simple, wormlike creature having these features. . . . From this primitive segmented worm the annelids have been directly evolved with little addition other than the development of segmental groups of lateral bristles, . . . the so-called parapodia, that serve for swimming and burrowing.
>
> By a different type of specialization for locomotion, members of another branch from the ancestral stock developed ventrolateral lobelike outgrowths of the body segments, and thus became walking animals. These primitive legs eventually evolved into the jointed appendages of modern arthropods.

There are extant, he points out, animals that seem quite close to the stage at which the ancestors of the joint-legged animals had only lobelike outgrowths from the segments. These are the onychophorans, represented by the wormlike *Peripatus* of tropical America and Africia. There are several fossils of such creatures found in rocks which were formed prior to the Cambrian period in geological history, about a half billion years ago, when the earliest traces of higher animals are found. The extant onychophorans, Dr. Snodgrass points out, are probably direct descendants of the early lobe-legged creatures and structurally have not progressed much beyond them. In some of their probable contemporaries, however, structural changes in the rest of the body allowed the legs to become longer, slenderer, and finally jointed for more efficient locomotion.

better

elected
e non-
at im-
ne wis-
action.
ions of
ucture
etween
gree of
rovide
s, part
ded as

les and
teristic
roblem
sist of
l man-
repre-

f divi-
totle's
o that
n from
ndary
s non-

l para-
ving.
r loco-
m the
obelike
became
ntually
nodern

ls that
he an-
l only
These
y the
a and
eatures
to the
bout a
aces of
nycho-
obably
legged
gressed
obable
nges in
become
more